Android: forensics and reverse engineering

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Outline

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A few words on Android

Software:

- Linux kernel (patched)
- custom userland code: utilities, Bionic libc (BSD licensed)
- Java applications running on the Dalvik VM
- native code *via* JNI
- apps are (mainly) distributed on the marketplace

Hardware:

- mostly ARM but also MIPS, x86, PPC
- now powering TVs, tablets, ebook readers, etc.

Security model:

- one UID per application for isolation
- permission model for applications (GPS, phone, data, . . .)
- relies on the security of the Linux kernel

Applications: APK

APK content

```
classes.dex
AndroidManifest.xml
resources.arsc
lib/
lib/armeabi/
lib/armeabi/libhello-jni.so
META-INF/
META-INF/MANIFEST.MF
META-INF/CERT.RSA
META-INF/CERT.SF
res/
res/layout/
res/layout/main.xml
```

This talk

Covers:

- physical memory (RAM) acquisition and analysis
- filesystem acquisition and analysis
- application reverse engineering

Does not cover:

- user data forensics (SMS, emails, etc.), use existing tools
- device specific tricks: jailbreaking/rooting, etc.

Research to create the SSTIC challenge:

- French IT security conference
- included forensics, reverse and cryptography
- awesome solutions (in French, except one) online

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The challenge

Android is a loosely defined platform:

- Android is just an upstream distribution (like kernel.org for Linux)
- manufacturers and carriers can and do customize it
- hardware varies: CPU, GPU, accessories
- evolution is extremely fast: 5 major releases in 1.5 years

Rogue apps exist:

- Jon Oberheide PoC *RootStrap*
- applications leaking informations (see TaintDroid)

Forensics experts need be able to deal with all these factors

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Got root ?

The root issue:

- most phones have **NO** root access
- root access is needed to dump the RAM and filesystems
- most root exploits, if they exist, need a reboot
- trust the exploit ? UniversalAndroot has 800K of ELF binaries
- a reboot means losing a lot of potentially interesting data

A broken model:

- carriers lock users out, are slow to push out updates
- old, unsupported versions still distributed
- bad guys can root your phone using unpatched vulnerabilities
- you should not have to use vulnerabilities yourself to check/fix your system !

The following assumes root access, an ideal situation

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Memory: acquisition

Usual way on Linux:

- parse `/proc/iomem` to identify RAM mappings
- dd on `/dev/mem` if it's present (no `STRICT_DEVMEM` on ARM)
- use a kernel module (like *fmem*) if `/dev/mem` doesn't exist

It gets uglier:

- unfortunately, `/dev/mem` is not always present (HTC, Acer)
- kernel modules are version, .config and compiler dependent
- that's easy (in theory): get the source !
  - is it available ?
  - is it really the exact version ?
  - even if the GPL mandates it, it's not always perfect
- .config: `/proc/config.gz`, if it's enabled !

In practice it can take hours for each model

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Memory: analysis, generic

Rather well documented for x86, most common tasks include:

1- rebuilding processes
2- identifying open files
3- recovering open sockets

Usual way:

- identify structure member offsets for the given kernel version
- find the *pid 0* task using it's *comm* field (swapper)
- walk the linked list of processes
- use the *mm_struct* to rebuild the virtual address space
- parse VMAs to identify files

ARM is basically the same but ...

Memory: analysis, Android

Some specificities:

- RAM is not always mapped at address 0
- RAM may be split
- `PAGE_OFFSET` varies
- *kallsyms* seems to always be present
- no public tools (except SSTIC challenge solutions)

Promising research to apply: *kmem_cache*:

- used for fixed-size allocation in the kernel
- the SLAB allocator keeps more data than SLUB
- all phones seem to use the SLAB allocator
- useful for sockets, dead processes

But this is not the only way...

Memory: running apps

APK are just ZIP, why not carve them ?

- ZIP has a lot of redundant metadata:
  - each packed file is a described by a *local file header* (LFH)
  - at the end, several *central directory headers* (CDH) point to all previous LFH
  - finally, a *end of central directory record* (EOCDR) terminates the archive
- rebuilding:
  1- identify all EOCDR
  2- check if the first CDH is in the same page, if not, look for it
  3- collect the filename, sizes and CRC from each CDH
  4- find the matching LFH

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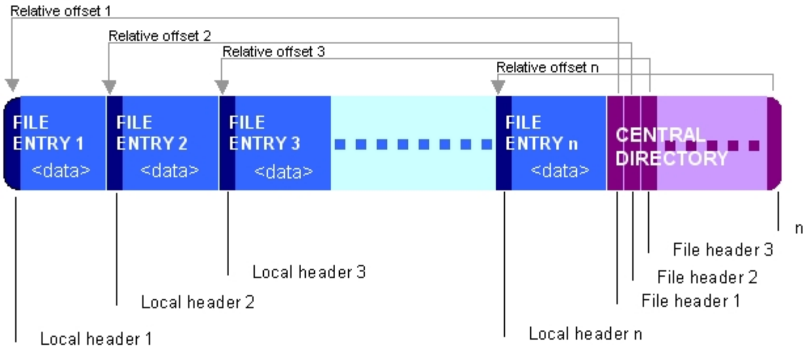
ZIP file format



Source: Wikipedia

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Memory: running apps

So far so good, but what about fragmentation ?

- pages are 4096 bytes
- but ZIP streams are compressed and their entropy high
- the last page of a stream is followed by a LFH or a CDH

In practice:

- works only on small archives (exponential number of combinations)
- easier to implement than full memory analysis (no kernel dependancy)
- real world example: a few minutes to analyze a 96MB dump with a python implementation

One can also try to dump (small) dex files directly (magic number)

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Filesystem: acquisition

Prerequisites:

- root access is still required
- but rebooting should not be destructive

Two main acquisition techniques:

- use *dd* or *nanddump* to dump mtdblocks to the SD card
- use Nandroid to directly dump the files to the host computer

YAFFS2:

- log-based filesystem, designed for NAND
- use *yaffs2utils* or *unyaffs* to extract files
- data recovery should be investigated (wear leveling)

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Filesystem: analysis

Most of the information is easy to get in `/data`:

- installed packages: `/data/system/packages.xml`
- `dalvik-cache` contains ODEX files
- the `checkin.db` database contains info on connections
- application specific sqlite databases

Applications are installed in */data/app*

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Reverse: the dalvik VM

Dalvik:

- java bytecode is converted to dalvik opcodes (*classes.dex*)
- VM is register based instead of stack based
- native code is available *via* JNI (*Java Native Interface*)

Applications, APK:

- Dalvik code (*classes.dex*)
- native code (*.so*)
- ressources (images, interface, data)
- manifest and signature (app signing is mandatory, but self-signed accepted)

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Reverse: disassembly, example source

Standard RC4 code in Java

```
byte getbyte() {
    int x, y;
    byte sx, sy;

    x = (this.x + 1)&0xFF;
    sx = state[x];
    y = (sx + this.y)&0xFF;
    sy = state[y];
    this.x = x;
    this.y = y;
    state[y] = sx;
    state[x] = sy;

    return state[(sx + sy) & 0xff];
}
```

Reverse: disassembly: dexdump

Android SDK *dexdump* output

```
|[000a98] com.anssi.secret.RC4.getbyte:()B
|0000: iget v4, v6, Lcom/anssi/secret/RC4;.x:I // field@0011
|0002: add-int/lit8 v4, v4, #int 1 // #01
|0004: and-int/lit16 v2, v4, #int 255 // #00ff
|0006: iget-object v4, v6, Lcom/anssi/secret/RC4;.state:[B // field@0010
|0008: aget-byte v0, v4, v2
|000a: iget v4, v6, Lcom/anssi/secret/RC4;.y:I // field@0012
|000c: add-int/2addr v4, v0
|000d: and-int/lit16 v3, v4, #int 255 // #00ff
|000f: iget-object v4, v6, Lcom/anssi/secret/RC4;.state:[B // field@0010
|0011: aget-byte v1, v4, v3
|0013: iput v2, v6, Lcom/anssi/secret/RC4;.x:I // field@0011
|0015: iput v3, v6, Lcom/anssi/secret/RC4;.y:I // field@0012
|0017: iget-object v4, v6, Lcom/anssi/secret/RC4;.state:[B // field@0010
|0019: aput-byte v0, v4, v3
|001b: iget-object v4, v6, Lcom/anssi/secret/RC4;.state:[B // field@0010
|001d: aput-byte v1, v4, v2
|001f: iget-object v4, v6, Lcom/anssi/secret/RC4;.state:[B // field@0010
|0021: add-int v5, v0, v1
|0023: and-int/lit16 v5, v5, #int 255 // #00ff
|0025: aget-byte v4, v4, v5
|0027: return v4
```

Reverse: disassembly: dexdump

Android SDK *dexdump* output

```
com.anssi.secret.RC4.getbyte:()B

iget v4, v6, Lcom/anssi/secret/RC4;.x:I
add-int/lit8 v4, v4, #int 1
and-int/lit16 v2, v4, #int 255
iget-object v4, v6, Lcom/anssi/secret/RC4;
                                    .state:[B
aget-byte v0, v4, v2
iget v4, v6, Lcom/anssi/secret/RC4;.y:I
```

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Reverse: tools

baksmali/smali:

- disassembler / assembler
- easier to use than *dexdump*
- allows code modification and recompilation
- handles APK directly

android-apktool:

- decodes/encodes resources
- includes smali/baksmali
- allows smali code debugging

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Reverse: decompilation

Several tools convert the dex code back to standard Java bytecode:

- *undx* was the first one presented:
  - more a PoC: fails often
  - resulting code isn't optimal
  - recent fork ig-undx may be better
- *dex2jar*:
  - mostly documented in Chinese
  - works quite well

Use jd-gui or Jad to decompile resulting jar

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Reverse: decompilation

dex2jar output

```
byte getbyte()
{
  int i = this.x + 1 & 0xFF;
  int j = this.state[i];
  int k = this.y + j & 0xFF;
  int m = this.state[k];
  this.x = i;
  this.y = k;
  this.state[k] = j;
  this.state[i] = m;
  byte[] arrayOfByte = this.state;
  int n = j + m & 0xFF;
  return arrayOfByte[n];
}
```

Reverse: ODEX

Dalvik special case: ODEX

- *Optimized DEX*
- platform-specific optimizations:
  - specific bytecode
  - vtables for methods
  - offsets for attributes
  - method inlining
- the code is way harder to read
- dex files recovered from memory are ODEX
- */data/dalvik-cache* contains ODEX

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Reverse: ODEX

ODEX disassembly

```
|0000: +iget-quick v4, v6, [obj+000c]
|0045: +invoke-virtual-quick {v8}, [000d]
```

baksmali handles (deodex) ODEX code

- but needs all dependancies to resolve offsets

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Reverse: JNI

JNI is the same in Dalvik as in Java:

- an external *.so* is loaded
- methods must use the **JNIEnv** structure to exchange information
- types must be converted to native type from Java types
- otherwise just native code: syscalls, libs, ...

JNI specificities can ease reversing (compared to standard C):

1- get the function signature in Java

2- use IDA to generate a TIL file from *jni.h*

3- assign the structure to the right variable

4- see function calls directly

5- do the same in Hex-Rays

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Reverse: JNI

1

```
.text:0000173C    MOV     R8, R3
.text:0000173E    MOVS    R3, 0x2A4
.text:00001742    LDR     R3, [R2,R3]
.text:00001744    MOV     R9, R1
.text:00001746    MOVS    R2, #0
.text:00001748    LDR     R1, [SP,#0x1D0+var_1BC]
.text:0000174A    MOVS    R7, R0
.text:0000174C    BLX     R3
```

2

```
.text:0000173E    MOVS    R3, 0x
.text:00001742    LDR     R3, [F
.text:00001744    MOV     R9, R1
.text:00001746    MOVS    R2, #0
.text:00001748    LDR     R1, [S
.text:0000174A    MOVS    R7, RC
.text:0000174C    BLX     R3
.text:0000174E    LDR     R3, =
```

Chart of xrefs from
JNINativeInterface.GetStringUTFChars
Use standard symbolic constant
676 H
01244
0b1010100100 B

3

```
.text:0000173C    MOV     R8, R3
.text:0000173E    MOVS    R3, JNINativeInterface.GetStringUTFChars
.text:00001742    LDR     R3, [R2,R3]
.text:00001744    MOV     R9, R1
.text:00001746    MOVS    R2, #0
.text:00001748    LDR     R1, [SP,#0x1D0+var_1BC]
.text:0000174A    MOVS    R7, R0
.text:0000174C    BLX     R3
```

Reverse: JNI with Hex-Rays

```
v13 = strlen(v23);
8j3zIX(&v25, v23, v13, 0);
8j3zIX(&v25, v36, 32, 0);
sdlHj(&v25, &v32);
v22 = &v32;
((void (__fastcall *)(JNIEnv *, int, _DWORD, signed int))(*jnienv_)->SetByteArrayRegion)(jnienv_, v24, 0, 32);
i = 0;
do
{
  v26[i] = v33[i] ^ v36[i & 7];
  ++i;
}
while ( i != 17 );
v27 = v26[0] ^ 0x31;
v28 = v26[1] ^ 0x2C;
v29 = v26[2] ^ 0x59;
v30 = v26[3] ^ 0x2F;
v15 = ((int (__fastcall *)(JNIEnv *, unsigned __int8 *))(*jnienv_)->FindClass)(jnienv_, v26);
```

```
(*jnienv_)->SetByteArrayRegion)(jnienv_, v24, 0, 32);
```

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The future

Needed:

- complete (reliable) tools for memory analysis
- advanced tools for filesystem analysis

The next steps:

- Android 2.2 introduced JIT, big deal ?
- virtualisation (Acer Betouch E130)
- handle all kinds of CPUs
- more and more diversity to come

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