



DEPARTMENT OF INFORMATICS

TECHNISCHE UNIVERSITÄT MÜNCHEN

Master's Thesis in Informatics

**Analysis of Android Cracking Tools and
Investigations in Counter Measurements
for Developers**

Johannes Neutze, B. Sc.





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**Analyse von Android Crackingtools und Untersuchung
geeigneter Gegenmaßnahmen für Entwickler**

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Submission Date:	March 15, 2015



I confirm that this master's thesis in informatics is my own work and I have documented all sources and material used.

Munich, March 15, 2015

Johannes Neutze, B. Sc.

Acknowledgments

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Assumptions

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Abstract

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Contents

Acknowledgments	iii
Assumptions	iv
Abstract	v
Glossary	1
Acronyms	2
1 Introduction	4
1.1 Licensing	4
1.2 Motivation	4
2 Foundation	6
2.1 Software Piracy	6
2.1.1 Developers	6
2.1.2 Users	7
2.1.3 Android	8
2.2 Android	8
2.2.1 Android Application Package (APK)	9
2.2.2 Dalvik Executable File Format	11
2.2.3 Installing an APK	13
2.2.4 Dalvik Virtual Machine	13
2.2.5 Android Runtime	14
2.2.6 Copy Protection and Root	17
2.3 License Verification Libraries	18
2.3.1 Google's License Verification Library (LVL)	19
2.3.2 Amazon DRM (Kiwi)	23
2.3.3 Samsung DRM (Zirconia)	25
2.3.4 Abstraction	27
2.4 Code Analysis	27
2.4.1 Retrieving an APK	30

2.4.2	dex Analysis	31
2.4.3	Smali Analysis	32
2.4.4	Java Analysis	34
2.4.5	Detect Code Manipulations	37
3	Cracking Android Applications with LuckyPatcher	38
3.1	LuckyPatcher	38
3.2	Code Manipulation	39
3.3	Cracking License Verification	41
3.4	Patching Patterns	41
3.5	Learnings and Conclusion	50
4	Counter Measurements for Developers	51
4.1	Extend Current Library	51
4.1.1	Modifications on the Google LVL	51
4.1.2	Tampering Protection	53
4.1.3	Tampering Protection	58
4.2	Replace Existing Mechanism	63
4.2.1	Content Server	63
4.2.2	Encryption	64
4.3	Extensions to Environment	67
4.3.1	Trusted Execution Environment	68
4.3.2	ART	69
5	Conclusion	73
5.1	Summary	73
5.2	Discussion	73
5.3	Future Work	74
	List of Figures	76
	List of Tables	77
	List of Code Snippets	78
	Bibliography	80

Glossary

- .class** Java Byte Code produced by the Java compiler from a .java file.
- .dex** Dalvik Byte Code file, translated from the Java bytecode. Dalvik Executables are designed to run on system with memory or processor constraints. For example, the .dex file of the Phone application is inside the system/app/Phone.apk.
- .jar** The Java Archive is a package file containing Java class files and the associated metadata and resources of applications of the Java platform..
- .odex** Optimized Dalvik Byte Code file are Dalvik Executables optimized for the current device the application is running on. For example, the .odex file of the Phone application is system/app/Phone.odex.
- ADB** The Android Debug Bridge is a command-line application providing different debugging tools.
- API** The Android Debug Bridge is a command-line application providing different debugging tools.
- APK** An Android Application Package is the file format used for distributing and installing applications on the Android operating system. It contains the applications assets, code (.dex file), manifest and resources.
- assembler** Ein Assembler (auch Assemblierer[1]) ist ein Computerprogramm, das Assemblersprache in Maschinsprache übersetzt, beispielsweise den Assemblersprachentext „CLI“ in den Maschinsprachentext „11111010“..
- disassembler** Ein Disassembler ist ein Computerprogramm, das die binär kodierte Maschinsprache eines ausführbaren Programmes in eine für Menschen lesbarere Assemblersprache umwandelt. Seine Funktionalität ist der eines Assemblers entgegengesetzt..

Acronyms

.dex Dalvik EXecutable file.

.jar Java Archive.

.odex Optimized Dalvik EXecutable file.

ADB Android Debug Bridge.

ADT Android Developer Tools.

AOT Ahead-Of-Time.

APK Application Programming Interface.

APK Android Application Package.

ART Android RunTime.

DRM Digital Rights Management.

DVM Dalvik Virtual Machine.

ELF Extensible Linking Format.

GC Garbage Collection.

IP Intellectual Property.

JIT Just-In-Time.

JNI Java Native Interface.

JVM Java Virtual Machine.

LLVM Low Level Virtual Machine.

LVL License Verification Library.

NDK Native Development Kit.

OS operating system.

SDK Software Development Kit.

VM virtual machine.

1 Introduction

1.1 Licensing

Software Licensing is the legally binding agreement between two parties regarding the purchase, installation and use of software according to its terms of use. It defines the rights of the licensor and the licensee. On the one hand, the goal is to protect the software creator's Intellectual Property (IP) or other features and enable him to commercialize it as a product. On the other hand it defines the boundaries of usage for the user and prevents him from illicit usage [59].

Software licenses come in different variants. They range from open source to providing limited features or usage for a limited time to purchase only. Since using the full feature set of software might be bound to paying a royalty fee, these software is often subject of piracy. In order to prevent unauthorized use, mechanisms are implemented to enforce the legal agreement. This includes Digital Right Management solutions which deny access to the software in case of a wrong serial key or unregistered account.

The problem is that these mechanisms do not offer absolute security and pirates always try to circumvent them. This results in an everlasting armsrace between software creators and software thefts [60].

1.2 Motivation

Licensing is present in Android as well. According to Google's in September 2015 there were over 1.4 billion active devices in the last 30 days and a market share of almost 82.8% in Q2 of 2015 [24][37]. This giant number of Android devices is powered by Google Play [35], Google's marketplace. It offers different kinds of digital goods, as movies, music or ebooks, but also hardware. In the application section of Google Play user can chose from over 1.6 million applications for Android [63]. In 2014 Google's marketplace overtook Apple's Appstore, which had a revenue of over 10 billion in 2013, and became the biggest application store on a mobile platform [42].

The growth has many advantages. Some time ago developers only considered iOS user

as profitable and thus most applications were developed for Apple's Operating System (OS). Now with this reach and potential users they also focus on Android[50]. But there are downsides as well. The expanding market for Android, offering many high quality applications, also draws the attention of software pirates. Crackers do not only to bypass license mechanisms and offer applications for free. Redirecting cash flows or distributing malware using plagiates is an lucrative business model as well. Android developers are aware of the situation [66] and express their need to protect their IP on platforms like xda-developers [55] or stackoverflow [57]. Many of the developers having problems with the license verification mechanism name Lucky Patcher as one of their biggest problems [58].

The scope of this thesis is to analyse Android cracking applications and to investigate in counter measurements for developers.

2 Foundation

Before understanding the attack mechanisms and discussing counter measurements, necessary background knowledge has to be provided. Motivation and risks of software piracy and the basics of Android will be explained as well as existing licensing solutions. In addition, reengineering tools and methodologies for app analysis are described.

2.1 Software Piracy

According to Apple, 11 billion Dollars are lost each year due to piracy. Software piracy is defined as unauthorized reproduction, distribution and selling of software [19]. It includes the infringement of the terms of use of software by an individual as well as commercial resale of illegal software. Piracy is subject on all platforms and is considered stealing.

2.1.1 Developers

Especially for software developers piracy is a problem. The most apparent issue is clear at first glance. Stealing a developer's IP and redistributing without his involvement results in a loss of revenue. People are then downloading an application either for free or pay the pirate and thus do not generate revenue for the originator.

At second glance, the problems are even more complex. Income for the developer is not only lost when the user is not paying for the software, the pirate can also influence the follow up revenue by modifying the application itself. There are two main types of revenue not generated by the purchase of the application. The first type is the inapp purchase. They are a popular source of income for so called freemium applications or lite versions of apps. In case of the the freemium app, the download is for free and includes all features. Inapp purchases, e.g. inapp currency, enable the user to proceed faster or to buy cosmetic modifications. The lite version application is a little bit different. The download is free as well but the application comes with a restricted feature set or limited time of use. In order to take advantage of the unlocked feature set the user can buy the full license via inapp purchase. Apps can include a mix and various degrees of theses variants. Pirates can disable the payments for the features, enabling users to receive the inapp purchase for free and thus no earnings are generated

for the developer.

The second type of follow up revenue is generated by showing inappAds. When this feature is included, advertisements are shown inside the application and the developer is paid by the amount of ads seen and clicked by the user. The Ad Unit ID [34] is responsible to assign earnings generated by an mobile advertisement to the developer. When an application is pirated, this code can be replaced by the pirate's one. Future revenues generated by advertisements in the application will not be assigned to the developer but redirected to the pirate.

Beside monetary issues, additional problems arise when the app is moved to a black-market store or website and distributed without the environment of an official app store. This results in the loss of control over the application for the developer. This means the developer can no longer provide the users support or updates for the application to fix crashes caused by malfunctions or security issues. Users which do not know that they are using a pirated version will connect the unsatisfying behaviour to the developer. This can result in the loss of future revenues which are not even connected to this application. In addition to the loss over the application this can cause unpredictable scenarios. Since the developer cannot monitor the growth of the application over tools which are included in the market place of choice, he can face unpredictable high traffic. This can stress the server because they were not scaled according to the growth as well as additional costs caused by the traffic which is not covered by additional purchase income [45].

Developers have to live of their applications. When they do not earn money, either because the revenue stream is redirected or because their IP is stolen and commercialized by someone else, or even lose it due to maintaining costs, they cannot continue with developing and their skills are lost.

2.1.2 Users

Not only the loss of developers in the ecosystem is bad for user but also pirates can harm the users. Users use pirated applications because they seem to be free but it comes at a price. The application might be altered in different ways, e.g. malware can be included or it steals personal data by abusing changed permissions. The user will not notice it right away since these "features" often happen in the background without the knowledge of the user, e.g. send SMS using an expensive service or uploads the contacts to a database. Even if there is no malicious content implemented, the applications can suffer from bad stability due to removed license verification and missing updates when related from an unofficial source. In general the risk is very high that pirated software

has a worse user experience than the original. Pirated software should not be installed since it cannot be ensured without deep inspection that the application is doing what it is supposed to do. [23][45]

2.1.3 Android

Piracy is widespread on the Android platform. Especially in countries like China piracy is as high as 90% due to restricted access to Google Play [31]. Sources for pirated applications can be easily found on the internet. Simple searches containing "free apk" and the applications name return plenty of results on Google Search. The links direct to blackmarket applications, as Blackmart [21], and websites for cracked Android Application Package (APK), as crackApk [29]. These providers claim to be user friendly because they offer older versions of applications or do not charge money for complete version of applications. Their catalog includes premium apps which are not free in the Play Store and include license verification mechanisms. This is only possible when the license mechanism is cracked [18]. They practice professional stealing and are dangerous for users (see section 2.1.2). When downloading an APK it is not possible to guarantee the integrity of the program.

An example for the dimensions piracy can reach for a single application is "Today Calendar Pro". The developer stated in a Google+ post that the piracy rate of the application is as high as 85% at the given day. This results in only 15% being legitimately purchased and installed. [55][66]

Since license mechanisms are no obstacle for pirates, some developers do not implement any copy protection at all since it is cracked within days [39]. Especially Android applications are at high risk for piracy due to bytecode in general is an easy target to reverse engineer.

2.2 Android

Android is an open source mobile OS launched in 2007 and currently developed by Google. It is based on the Linux kernel and mainly targets touch screen devices such as mobile devices or wearables. The system is designed to run efficiently on battery powered devices with limited hardware and computational capacity. Android's main hardware platform is the ARM architecture since these processors with their low power consumption are often used in this scenario. The following will give an overview over the architecture of Android and a deeper insight in the runtime powering Android. The architecture of the software stack of Android can be seen in figure 2.1.



Figure 2.1: Android's architecture [48]

The basis of the system is its kernel. It is responsible for power and memory management and controls the device drivers. Software can use the provided hardware abstraction layer as well as execute standard Unix commands using the kernel. The layer above the kernel contains the Android Runtime, which will be explained in detail in section 2.2.5, as well as the native libraries of the system. Usually Android libraries are written in Java except the ones which are resource and time critical. They are written in C or C++ in order to boost performance and allow low level interaction between applications and the kernel by using the Java Native Interface (JNI). Examples for native libraries are OpenGL, multimedia playback or the SQLite database. On top of the libraries and the runtime lies the application framework. This layer provides generic functionality as notification support to applications over Android's Application Programming Interface (API). The most upper layer enables the installation and execution of applications. Using layers and abstraction enables Android to be run on a wide range of devices.

2.2.1 Android Application Package (APK)

Android applications are distributed and installed using the APK file format. They can either be obtained from an appstore, like Google Play, or downloaded and installed, manually or by using Android Debug Bridge (ADB), from any other source.

The APK format is based on the ZIP file archive format and contains the code and

resources of the application. The build process of APK contains several steps which are visualized in figure 2.2.

Since Android applications are usually written in Java, the first step is similar to the

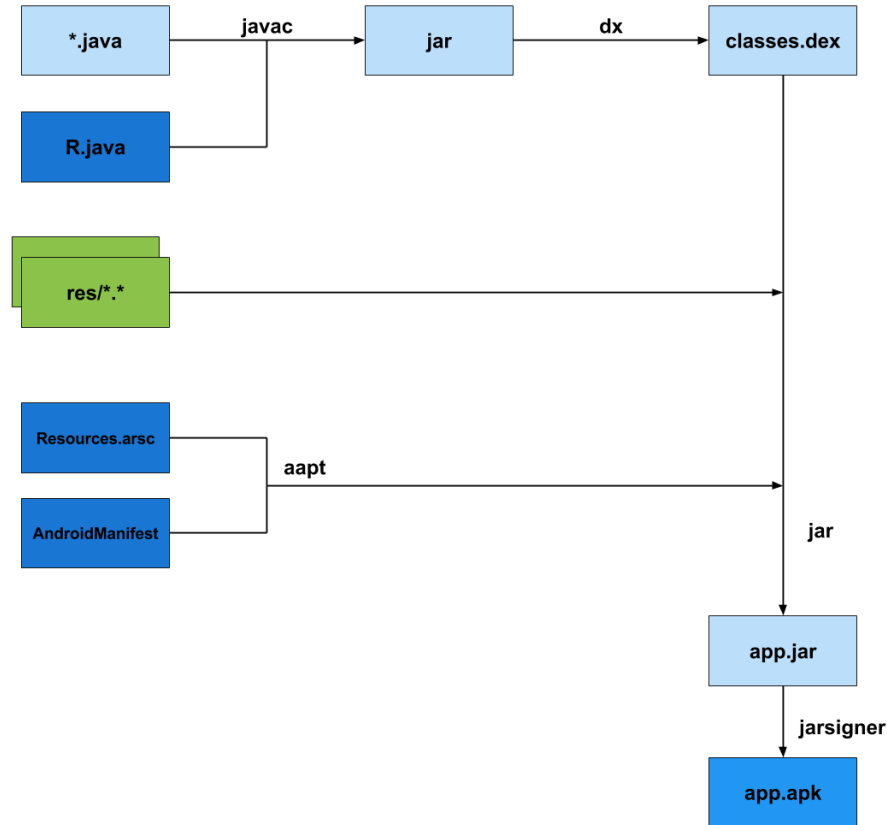


Figure 2.2: APK build process [44]

Java program build process. The Java source code is compiled into .class file by the Java Compiler javac. Each .class files contains the Java bytecode of the corresponding Java class. The structure of a .class file can be seen in figure 2.4. As an additional step in the Java compilation process a Java obfuscator can be applied (similar to section 4.1.3). In the end the .class files are packed into a Java Archive (.jar) file.

Since Android is using the Dalvik Virtual Machine (DVM), which will be described in section 2.2.4, the Java bytecode has to be converted to Dalvik bytecode. The Android Software Development Kit (SDK) includes the tool dx which is used to convert .class files to a single classes.dex file containing all classes. The Dalvik EXecutable (.dex) format will be described in 2.2.2. After this conversion additional obfuscation techniques

can be applied [30].

In the next step the ApkBuilder combines the three main parts of the application into one archive file. The first one is the classes.dex with the bytecode. The second part are the resources files which are added when present. These files are static content like images, layouts and the native code which is stored in shared object (.so) files. The third type of files are the resources.arsc file, which contain the compiled resources, and the Android Manifest, which gives essential information like needed permissions which have to be known before running the application.

In the fourth and final step the jarsigner adds the developers signature to the package. It does not improve security of the application itself but it makes it possible to identify the developer and by this allow actions like updates.

The final application file has the following folder structure. It contains different subfolders like lib, res, assets and META-INF as well as the resources.arsc, classes.dex and AndroidManifest.xml files. The lib folder contains subfolders with the compiled native code for the different processor types, like armeabi-v7a for ARM or x86 for Intel processors. Assets, which can be accessed inside the application code using the AssetManager, are in the assets folder. The resources are either in the res folder or, in case it is possible to compile them, stored in the resources.arsc. The last folder is the META-INF, which is inherited from Java, stores package and extension configuration data and other [49]. The classes.dex and AndroidManifest.xml are already covered. [41] [32]

2.2.2 Dalvik Executable File Format

As explained in chapter [subsection:foundation-android-package], Android applications deliver their code in .dex bytecode and are executed by the DVM. The dex file format is compiled from Java bytecode. It is similar to Java bytecode except some differences. The biggest difference is the concept how the code is executed. While the Java Virtual Machine (VM) is stack-based the DVM is register-based, this circumstances have influence on the code. In addition the Dalvik bytecode is more suited to run on the ARM architecture since it supports direct mapping from dex registers to the registers of the ARM processor. Registers in .dex bytecode are 32bits wide and store values such as integers or float values. In case there are 64bit values, adjacent registers are used to store it. The Java bytecode is actually more compact since it uses 8bit constants while .dex bytecode has instructions of 16bit multiples. The .dex bytecode supports 218 valid opcodes which have a dest-source ordering for its arguments. The arguments of the instruction refer to indexes in the pools which can be seen in figure 2.3.

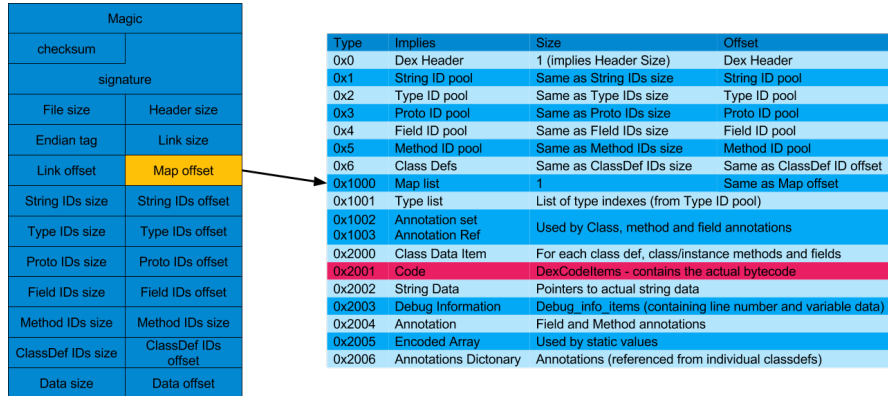


Figure 2.3: .dex file format [44]

In order to create the dex file, dx is used on the .jar file. Dx compiles the Java bytecode to .dex byte code and sorts string, type and method from the heterogeneous pool of each class into global pools. This results in figure 2.3 and figure 2.4.

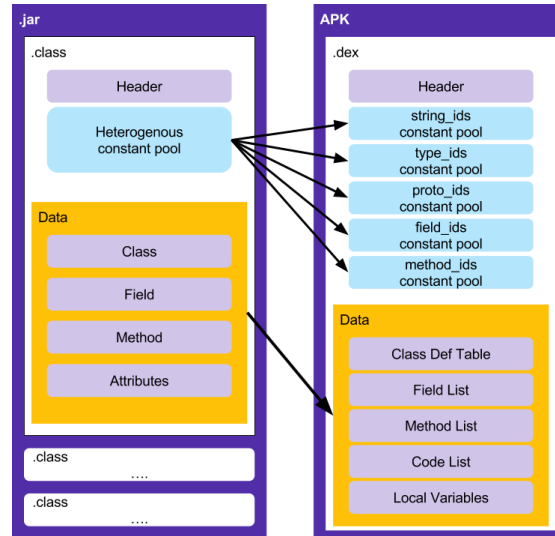


Figure 2.4: .jar to APK transformation [22]

When merging the resource pools, duplicates are removed. This is most effective for string and results in a decrease of the memory footprint by up to 44% lower in contrast to the .jar. The result is that the .dex file has significant more references than the .jar file. The .dex file is stored as classes.[32]

Since .dex bytecode supports optimization, improvements for the underlying architecture can be applied to the bytecode upon installation. The resulting .dex file is called Optimized Dalvik EXecutable (.odex). The optimizations are executed by a program called dexopt which is part of the Android platform. For the DVM it makes no difference whether .dex or .odex files are executed, except speed improvements. Bytecode has also a downside. Like Java bytecode, .dex bytecode allows easy decompilation to Java. Since the bytecode is, in contrast to other architectures, pretty simple to understand as well as protection is applied rarely since it has to be done by the developer itself, it is an easy target for reverse engineering.

2.2.3 Installing an APK

Now that the format of the APK and .dex file format are explained, the application can be installed. Before running an application, two steps are applied on the APK. The first step is primary about the verification of the application while the second step is the bytecode optimization and, in case of Android RunTime (ART), the code compilation. Before installing an application it is checked for a legitimate signature as well as correct classes.dex structure (see figure 2.5). In case this cannot be verified, the installation will be rejected by the OS. The second step is the optimization. In case the device is still running the DVM, the .odex version of the classes.dex is generated. This is possible because .dex files can be optimized in order to achieve the best performance for a given device architecture. This is due to the high diversity of Android running hardware and their different processors. In the process the classes.dex file is taken from the archive and put as .odex file into the Dalvik cache. This is done once and from then on the execution is done by using the .odex file. This preprocessed version of the application has an improved startup time. [41] The current versions of Android run on the ART. For this runtime the second step is more complex since the bytecode has to be compiled an additional time. This will be explained closer in section 2.2.5.

When the application is run later, Android is creating an sandboxed environment for each application. This is achieved by Android assigning each process a separate user ID on install to ensure that each application is isolated from the others and has no access on resources except its own. [10]

2.2.4 Dalvik Virtual Machine

The original VM powering Android is the DVM, which was created by Dan Bornstein and named after an Icelandic town. It was introduced along with Android in 2008 [16]. In contrast to a stationary computer a mobile device have a lot of constraints. Since

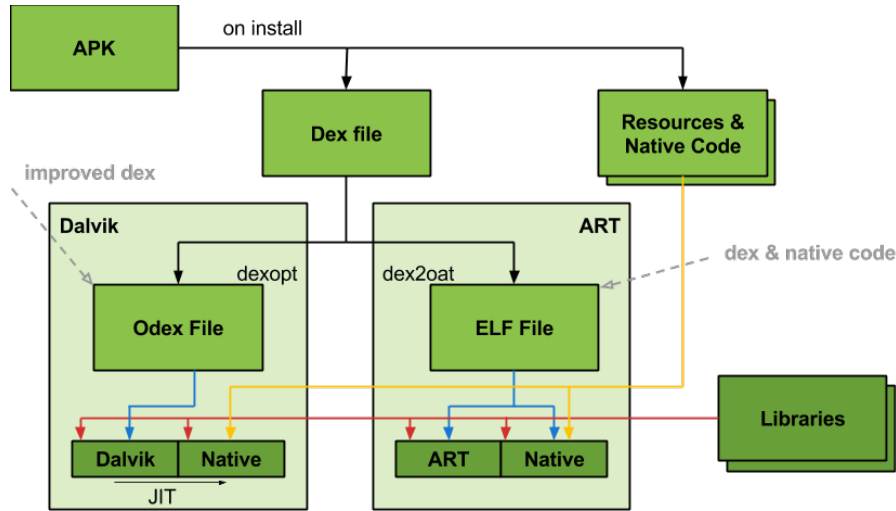


Figure 2.5: Installing an APK on a device [17]

they are powered by battery the processing power and RAM are limited to fit power consumption. In addition to these hardware limitations Android has some additional requirements, like no swap for the RAM, the need to run on a diverse set of devices and in a sandboxed application runtime. In order to deliver best performance and run efficiently it has to be designed according to these requirements. The DVM is a customized and optimized version of the Java Virtual Machine (JVM) and based on Apache Harmony. Even though it is based on Java, it is not fully J2SE or J2ME compatible since it uses 16bit opcodes and register-based architecture in contrast to the standard JVM being stack-based and using 8bit opcodes. The advantage of register-based architecture is that it needs less instructions for execution than stack-based architecture which results in less CPU cycles and thus less power consumption which is important for a battery driven device. The downside of this architecture is the fact that it has an approximately 25% larger codebase for the same application and negligible larger fetching times [32]. In addition to the lower level changes the DVM is optimized for memory sharing, it stores references bitmaps separately from objects and optimizes application startup by using zygotes [44].

The last big change made to the DVM was the introduction of Just-In-Time (JIT) in Android version 2.2 "Froyo".

2.2.5 Android Runtime

In Android version 4.4 "Kitkat" Google introduced ART which was optional and only available as a preview through the developer options. Like DVM, ART executes the .dex

fileformat und .dex bytecode specification [7]. With the release of version 5.0 "Lollipop" ART it became the runtime of choice since DVM had some major flaws. Throughout the Android 6.0 "Marshmallow" previews it was constantly evolving and sometimes breaking with older versions at the cost of almost no documentation.

ART is designed to address the shortcomings of the DVM. Maintaining an VM is expensive, having an interpreter and JIT is not as efficient as native code and doing JIT each time the application is executed is wasteful. This and maintaining background threads require significantly more CPU cycles which can be directly translated to slower performance and increased battery usage. In addition the Dalvik Garbage Collection (GC) frequently causes hangs and jitters and DVM is only supporting 32bit. With ART Android is following iOS into the 64bit world but this is not the only advantage over the DVM. Improvements in the VM make the maintenance less expensive and the compilation is changed from JIT to Ahead-Of-Time (AOT) as well as the overhead cycles have been reduced. The GC is also non-blocking now and can run parallel in fore- and background.

The main idea of ART and AOT is to compile the application to one of two types, either native code or Low Level Virtual Machine (LLVM) code. Each of the types has its purpose and advantage. The native code offers an improved execution performance while the LLVM code offers portability. In practice the preference is to compile to native since adding LLVM bitcode adds another layer of complexity to ART.

Different from DVM is the fact that ART uses not one but two file formats. Similar to the zygote of DVM, ART offers an image of pre-initialized classes and related objects at run time, the boot.art file. It is mapped to the memory upon zygote startup to provide improved application starting time [8]. The second file format is

Art itself: art uses not one but two file formats art - only one file, boot.art, in /system/framework/architecture (arm,...) oat - master file, boot.oat, in /system/framework/architecture (arm,...) - odex files no longer optimized dex but oat, alongside apk for system apps/frameworks, /data/dalvik-cache for 3rd party apps, still uses odex extension, now file format is elf/oat

art files is a proprietary format, poorly documented, changed format internally repeatedly art file maps in memory right before oat, which links with it contains pre-initialized classes, objects and support structures

ART/OAT files are created (on device or on host) by dex2oat art still optimizes dex but uses dex2oat instead, odex files are actually oat files (elf shared objects WAS IST DAS), actual dex payload buried deep inside command line saved inside oat file's key value store

art file format

art code generation oat method headers point to offset of native code each method

```

shell@flounder ~ dextra -h /system/framework/arm64/boot.oat
..
Key value store Len: 2318
    Key: debuggable      Value: false
    Key: dex2oat-cmdline Value: --runtime-arg -Xms64m --runtime-arg -Xmx64m --image-
classes=frameworks/base/preloaded-classes
--dex-file=out/target/common/obj/JAVA_LIBRARIES/core-libart_intermediates/javali.jar
--dex-file=out/target/common/obj/JAVA_LIBRARIES/conscrypt_intermediates/javali.jar
--dex-file=out/target/common/obj/JAVA_LIBRARIES/okhttp_intermediates/javali.jar
..
--dex-file=out/target/common/obj/JAVA_LIBRARIES/org.apache.http.legacy.boot_intermediates/javali.jar
--dex-location=/system/framework/core-libart.jar
...
--dex-location=/system/framework/org.apache.http.legacy.boot.jar
--oat-symbols=out/target/product/flounder/symbols/system/framework/arm64/boot.oat
--oat-file=out/target/product/flounder/dex_bootjars/system/framework/arm64/boot.oat
--oat-location=/system/framework/arm64/boot.oat
--image=out/target/product/flounder/dex_bootjars/system/framework/arm64/boot.art --base=0x70000000
--instruction-set=arm64 --instruction-set-variant=denver64 --instruction-set-features=default
--android-root=out/target/product/flounder/system --include-patch-information --runtime-arg
-Xnoelocate --no-generate-debug-info
    Key: dex2oat-host      Value: x86_64
    Key: pic               Value: false

```

Figure 2.6: oat

has a quick or portable method header, contains mapping from virtual register to underlying machine registers each method has a quick or portable frame info, provides frame size in bytes, core register spill mask, fp register spill mask generated code uses unusual registers, especially fond of using lr as call register, still saves/restores registers so as not to violate arm conventions

art supports multiple architectures(x86,arm/64,mips) compiler is layered architecture, using portable (llvm) adds another lvl with llvm bitcode (not in this scope)

the oat dexfile header oat headers are 1...n dex files, actual value given by dexfilecount field in header

finding dex in oat odex files will usually have only one (=original) dex embedded boot.oat is something else entirely, some 14 dex files the best of the android framework jars, each dex contains potentially hundreds of classes

lessons base code is dex so vm is still 32bit, no 64bit registers or operands so mapping to underlying arch inst always 64bit, there are actually a few 64bit instructions but most dex code doesn't use them generated code isn't always that efficient, not on same par as an optimizing native code compiler, likely to improve with llvm optimizations overall code (determined by Mir optimizations) flow is same garbage collection, register maps, likewise same caveats: not all methods guaranteed to be compiled, reversing can be quite a pain

isn't android all dalvik now? art is runtime but application compile into dex, art is compiled on device during install, art binaries has dalvik embedded, some methods may be left as dex to be interpreted, dalvik is much easier to debug than art –see-evaluation

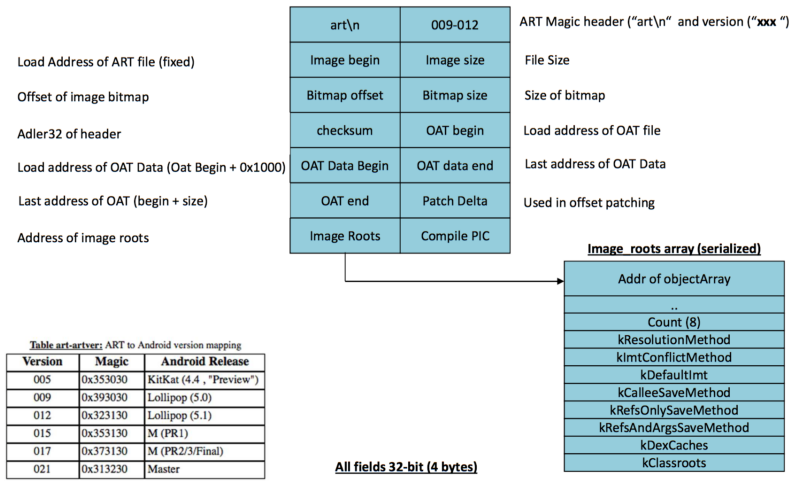


Figure 2.7: art

[44]

+

2.2.6 Copy Protection and Root

Now that the application is installed and ready to run. In order to prevent unauthorized usage of the app copy protection is applied. After downloading APK from an application store it is moved to /data/app on the phone upon installation. The user has no rights to access this folder and thus not copy the application. This mechanism has a major flow since when a single user can get hold of the APK and redistribute it, copy protection for the application is circumvented. This was effective in the early days of Android when rooting was not easily facilitated.

"Rooting" or "getting root" is the process of modifying the operation system's software that shipped with a device in order to get complete control over it. The name "root" comes from the Linux OS world and is the user with the most privileges. This allows the user to overcome limitations by carriers and manufacturers, like removing pre-installed applications, extend system functionality or to upgrade to custom versions of Android. Manufacturers and carriers do not approve rooting but since the access is usually gained by exploiting vulnerabilities in the system's code or device drivers, they cannot prevent it. Vulnerabilities are quite common and documented [androidVulnerabilities]. Today it is easy, even for non-techies, to gain root. There are videos and tutorials on the internet, even tools to automate the process, like Wugfresh's Rootkits [67], are available.

Lollipop (5.x)		Marshmallow (PR1)		Marshmallow (PR2-Release)	
art\n	009-012	art\n	015	art\n	017-???
Image begin	Image size	Image begin	Image size	Image begin	Image size
Bitmap offset	Bitmap size	ART Fields Offset	ART Fields Size	OAT checksum	OAT begin
checksum	OAT begin	Bitmap offset	Bitmap size	OAT Data begin	OAT Data end
OAT Data begin	OAT data end	checksum	OAT begin	OAT end	Patch Delta
OAT end	Patch Delta	OAT Data begin	OAT data end	Image Roots	Size of Pointer
Image Roots	Compile PIC	OAT end	Patch Delta	Compile_pic	Objects Offset
		Image Roots	Compile PIC	Objects Size	Fields Offset
				Fields Size	Methods offset
				Methods size	Strings Offset
				Strings size	Bitmap offset
				Bitmap size	

... Followed by Image Roots

All fields 32-bit (4 bytes)

Figure 2.8: art2

Rooting is usually bundles with installing a programm called "su" which manages the root access for applications which request it. Rooting a phone is not without risk since installing bad files can result in the so called "bricking" meaning the phone is nonfunctional since the software cannot be executed anymore.[46]

Even though rooting brings a lot of improvements to the table it is bad for the copy protection making it non-existent. For this reason new ways of protecting applications have to be invented.

2.3 License Verification Libraries

Since the original approach of subsection 2.2.6 was voided, another method had to be introduced. This topic is not only relevant to Google as the main of contributor to Android and provider of its biggest store. Since Android allows to install apps from unknown sources and not only the Google Play, other stores were created to get a piece of Google's Android pie. Some of the most widespread stores are from Amazon and Samsung. Amazon does not only have the Amazon Store but is also trying to create an own ecosystem by selling the Firetablets with an Amazon tailored flavor of Android at a low price tag. Another approach is Samsung pursuing. In addition to a store

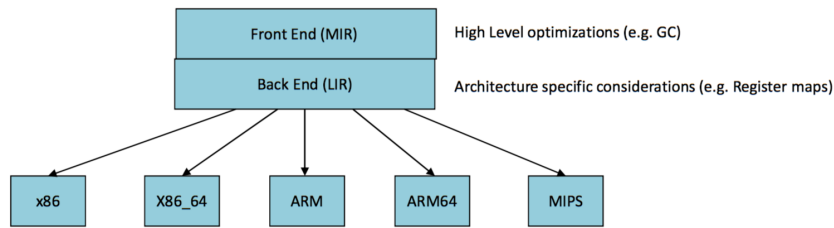


Figure 2.9: artarch

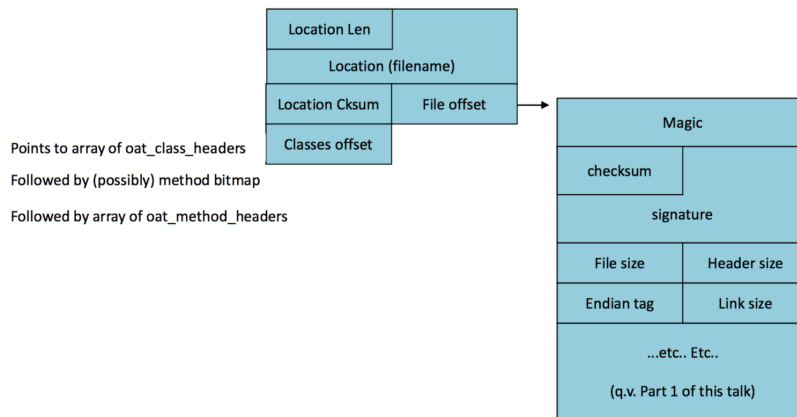


Figure 2.10: oatdex

they are also offering different services as well to bind to their ecosystem. There are different Chinese stores as well but they are out of scope since their relevance is bound to the eastern markets.

All these stores have to fight the copy protection problem in order make their store attractive and bind developers with low piracy rates. Since the initiative is coming from the stores, the copy protection methods are included into application itself. [47]

2.3.1 Google's License Verification Library (LVL)

In order to tackle the copy protection problematic and to give the developer community a possibility to fight piracy, Google introduced the License Verification Library (LVL) at 07/27/2010 [27]. It is simple and free of charges. The documentation can be found on the Android developers website. [12]

Functional Principle

Google's approach is a network service which allows to query the trusted Google Play license server in order to determine whether the user has a valid license. The library is provided by Google and the exact functionality can be studied by the developer since it is delivered in source code.[47]

It has to be manually integrated into the application by the developer and allows a simple checking with Google and has a callback for the reply. The developer can decide when and how often the application should check its license. Upon initiation, the library connects to the Google Play Service which manages the connection between the device and the license server. It sends a request for a license check on the server to determine the validity of the license, whether the application was bought by the user. This is similar to Digital Rights Management (DRM). Adding the library to the application does not alter the function of the application, it just adds a call. While the library takes care of the complicated process, like the networking and webservice, and returns the response of Google Play as soon as it arrives, the developer only has handle the callback. The developer is in full control what should happen with the response and whether access should be granted. Figure 2.11 gives an overview how the parts are connected. [40] [12]

In order to start the validation process with the Google Server und to determine the license status of the application, additional information has to be provided. The user has to initiate the call with the package name of the application, a nonce, which has to be included in every repsonse to ensure integrity, as well as the callback for asynchronous handling. The Google Play Service then adds the primary Google account the application is executed with, the IMSI of the device On the server Google checks whether the user has purchased the application and sends the corresponding response to the Google Play Service which passes it to the application. [12]

The security of the response is very important. It is achieved by public/private key encryption. Each published application in the Play Store has a pair of keys of which the developer has to integrate the public key, which is visible to him, into the application in order to decrypt the communication which is encrypted by the server with the private key. This way it the origin of the response is ensured as well as tampering detected. [47][12]

This results in some restrictions for the application to run. First of all, access to the internet is necessary as well since a connection to the Google Server has to be established. In case this is not possible, an internal error will be triggered which results in the license not being verified. Second of all, the Google Play Service has to be installed. It comes preinstalled with the Google Apps which includes the Google Play store. On the one hand, this is a prerequisite to legally aquire an application with the

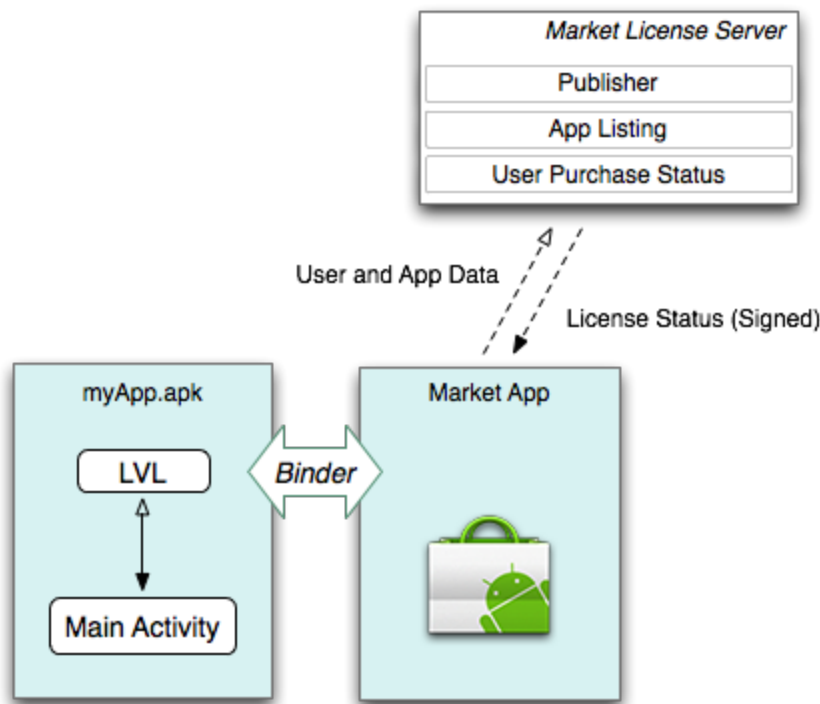


Figure 2.11: Google's implementation of license checking [12]

LVL. On the other hand, in case applications, with LVL implemented, cannot bind to the Google Play Service and thus cannot verify the license status. When the server is finally reached and the license is verified, it can be stored on the device and used in future requests in case no internet connection is available.[**developersLicensingAdding**][12] In summary this means the Google Play Service as well as a one time internet connection have to be present on the first startup in order to make the license check and, in case of the right answer, run the application. It replaces the old copy protection, which is no longer supported, with a secure mechanism to control access to the application. This license verification model can be enforced on all devices which have access to Google Play. [9] [12]

Implementation of the License Verification Library

The provided library of Google can be implemented in only a few steps. First of all, a Google Publisher Account for Google Play is needed. It enables the developer to publish applications on Google Play and take advantage of the LVL. As soon as an application is created in the Google Developer Console the public/private key is

created. Each key pair is app specific and can be found under "Services & API". It is later on added into the application. [14]

Now that the Google Play prerequisites are set, the LVL has to be extracted from the Android SDK folder and added to the application. As soon as the LVL is part of the application project the licensing permission can be added to the application's manifest (see code snippet 2.1), else the LVL will throw an exception. The last step is to create

```
7    ...
8    <uses-permission android:name="com.android.vending.CHECK_LICENSE" />
9    ...
```

Code Snippet 2.1: Include permission to check the license in AndroidManifest.xml [9]

the license call which can be seen in code snippet 2.2. As described in subsection 2.3.1,

```
57    final String mAndroidId = Settings.Secure.getString(this.getContentResolverSettings.Secure.
58        ANDROID_ID);
59    final AESObfuscator mObfuscator = new AESObfuscator(SALT, getPackageName(),
60        mAndroidId);
61    final ServerManagedPolicy serverPolicy = new ServerManagedPolicy(this, mObfuscator);
62    mLicenseCheckerCallback = new MyLicenseCheckerCallback();
63    mChecker = new LicenseChecker(this, serverPolicy, BASE64_PUBLIC_KEY);
64    mChecker.checkAccess(mLicenseCheckerCallback);
```

Code Snippet 2.2: Setting up the LVL license check call

different information has to be acquired and added to the license request. In order to identify the user the its unique id is acquired. The id is created randomly when the user sets up the device for the first time and remains the same for the lifetime of the user's device [15]. The obfuscator is later applied on the cached license response data to prevent manipulation or reuse by root user. In order to decide what should happen to the reponse data and whether it should be stored, a policy is specified. This can be either one of the provided policies are a custom one. Before making the license check request, a callback has to be definiden, which can be seen in code snipped ???. The callback contains actions for the different outcomes of the license check. The scenarios are either applicationError, e.g. when no connection can be established, dontAllow in case license is not valid and allow when the users status is verified. Now the license check can be initiated with the values. [14] [9]

The license check can be implemented in any activity and executed as the developer likes.

```
57
58     @Override
59     public void allow(final int reason) {
60         ...
61     }
62
63     @Override
64     public void dontAllow(final int reason) {
65         ...
66     }
67
68     @Override
69     public void applicationError(final int errorCode) {
70         ...
71     }
72 }
73 }
```

Code Snippet 2.3: LVL license check callback

2.3.2 Amazon DRM (Kiwi)

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As an alternative to Google Play, started its own appstore in October 2010 with the goal to generate profits from selling apps on Android as well [5]. It was opened to the public on the 03/22/2011 for Android and Fire tablets [6]. The store comes with its own DRM since the Google LVL only works with the Google Play Store. The developer can chose whether it should be enabled in the developer console in their developer console. named Kiwi (taken from decompilation) [4]

Functional Principle

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sis is text was sind voraussetzungen? amazon app, account active der die app hat

high level prerequisites amazon developer account

when uploading the app, user is asked whether

different approach to perform license verification and enforce result google lvl include and integrate modified version of lvl library, not required to implement any mechanism on their own, done by amazon packaging tool when submitting can check amazon DRM (see picture), apply amazon DRM to "Protect your application from unauthorized use. Without DRM, your app can be used without restrictions by any user." as the

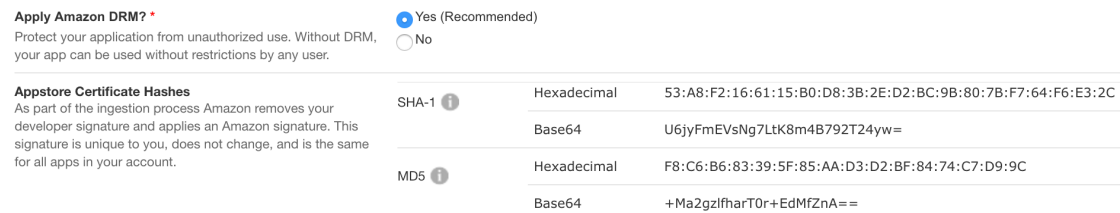


Figure 2.12: Developer preferences in the Amazon developer console [4]



Figure 2.13: Amazon library structure in decompiled application

description says "As part of the ingestion process Amazon removes your developer signature and applies an Amazon signature. This signature is unique to you, does not change, and is the same for all apps in your account." as the description says, so developer signing the application by the developer before submitting is not necessary, amazon decompiles apk, injects drm code, compiles it and signs it with the "amazon developer" certificate [47]

amazon appstore has to be installed the whole time and user has to be logged in order that the DRM works

airplane first time activity, callback: license not verified second time stored license

Implementation of Kiwi

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kind of wrapper no sample implementation to add by developer but inject own logic in each app (same for every app)

example shows implementation recovered by reengineering explained in 2.4 amazon drm contains numerous namespaces and classes, most have been mangled by obfuscation tools, see proguard startup in main activity myActivity drm logic not interweaved with app logic, could only be done by a human developer anyways

[47]

rename onCreate to onCreateMainActivity start in new onCreate, also start Kiwi.onCreate((Activity) this, true); which handles the


```
77 public void onCreate(Bundle bundle) {  
78     onCreateMainActivity(bundle);  
79     Kiwi.onCreate((Activity) this, true);  
80 }
```

Code Snippet 2.4: Amazon's onCreate() injection to call Kiwi license verification as well

2.3.3 Samsung DRM (Zirconia)

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Samsung as a major player in the smartphone business has also his own app store [28] Galaxy Apps by Samsung, formerly known as Samsung Apps, for devices by Samsung renamed in July 2015 called zirconia for android [53]

Functional Principle

This is my real text! Rest might be copied or not be checked!

library providing preventive measure against illegal reproduction works only on samsung devices since samsung store has to be installed and logged in inspects the license of application executed to prevent illegal use checks for license from license server upon init and stores it on device for future offline check, timed life also checks if license from server if stored license has been removed or damaged, license from server unique for each device/application if app is copied to another device, application will not execute

interior process: makes query for stored licensetest if found, app can execute if not exist or invalid, information of device and application will be send to server (once stored internet connection not required anymore) if purchased for device, server returns license back to zirconia zirconia stores license on device return step 1

callback method, asynch, zirconia does not return license validity result as boolean 2.6 does not work if network is offline or in airplane

[53]

no store services needed, direct communication with server

airplane first time activity, callback: license not verified second time verified if license was stored

Implementation of Zirconia

This is my real text! Rest might be copied or not be checked!

java package .jar and JNI native library have to be added to project for check and query of license server zirconia needs device info and internet connection (READ_PHONE_STATE

and INTERNET permission)

4 basics steps (see 2.5) create

can be implemented in any stage of the application, e.g. start or when saving
[53]

```
57  final Zirconia zirconia = new Zirconia(this);
58  final MyLicenseCheckListener listener = new MyLicenseCheckListener();
59  listener.mHandler = mHandler;
60  listener.mTextView = mStatusText;
61  zirconia.setLicenseCheckListener(listener);
62  zirconia.checkLicense(false, false);
```

Code Snippet 2.5: Setting up the Zirconia license check call

```
57  @Override
58  public void licenseCheckedAsValid() {
59      mHandler.post(new Runnable() {
60          public void run() {
61              ...
62          }
63      });
64  }
65
66  @Override
67  public void licenseCheckedAsInvalid() {
68      mHandler.post(new Runnable() {
69          public void run() {
70              ...
71          }
72      });
73  }
```

Code Snippet 2.6: Zirconia license check callback

First looks great, puts the copy protection inside the app, a from of DRM
communicate with server, authorize use of application
does not prevent user from copying/transferring app, but copy useless since the app
does run without the correct account
google die ersten, andere folgen, anfangs problem, dass dadurch nur durch google
store geschützt war, grund dafür dass evtl ein programmierer in meinen store kommt

2.3.4 Abstraction

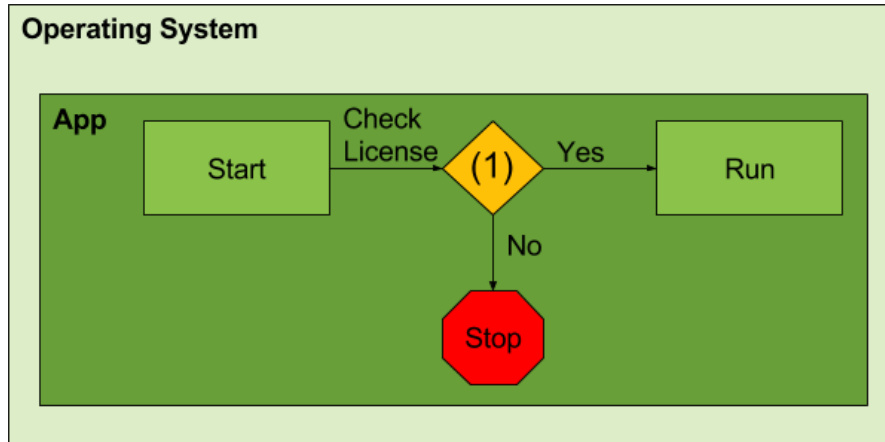


Figure 2.14: Abstraction of the current license verification mechanism. The library is represented by (1)

basiert einzig auf der antwort vom server die ja oder nein ist

but there are problems as well android's content protection are invalid when rooted
DRM can be bypassed coupled with dex decompilation big problem, app can be decompiled, modded and repackaged[43]

2.4 Code Analysis

The Cracking Tool has to alter an application's behaviour by applying patches only to the APK file, since it is the only source of code on the phone. This is the reason for the investigations to start with analysing the APK. This is done using static analysis tools. The aim is to get an accurate overview of how the circumventing of the license verification mechanism is achieved. This knowledge is later used to find counter measurements to prevent the specific Cracking Tool from succeeding.

The reengineering has to be done by using different layers of abstraction. The first reason is because it is very difficult to conclude from the altered bytecode, which is not human-readable, to the new behaviour of the application. The second reason is because the changes in the Java code are interpreted by the decompiler, which might not reflect the exact behaviour of the code or even worse, cannot be translated at all.

These problems are encountered by analysing the different abstraction levels of code as well as different decompilers.

recover the original code of an application bytecode analysis is most often used. By

applying both dynamic and static techniques to detect how behavior is altered dynamic analysis during runtime, static raw code, done by automatic tools using reverse engineering algorithms, best case whole code recovered, worst case none

When speaking of reverse engineering an Android application we mostly mean to reverse engineer the bytecode located in the dex file of this application.

The classes.dex file is a crucial component regarding the application's code security because a reverse engineering attempt is considered successful when the targeted source code has been recovered from the bytecode analysis. Hence studying the DEX file format together with the Dalvik opcode structure is tightly related to both designing a powerful obfuscation technique or an efficient bytecode analysis tool. [41]

dex to java .dex and .class are isomorphic dex debug items map dex offsets to java line numbers tools like dex2jar can easily decompile from dex to a jar extremely useful for reverse engineering, even more so useful for malice

flow from dex to java is bidirectional, decompile code back to java, remove annoyances

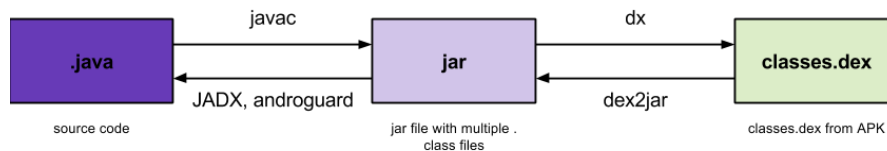


Figure 2.15: Java .class and .dex can be transformed bidirectional [44]

like ads, registration, uncover sensitive data (app logic, secrets), replace certain classes with others (malicious ones), recompile back to jar, then dex, put cloned/trojaned version of your app on play or other market [44]

android vulnerability of app is reverse engineering the source code, patching security mechanism and recompiling the app best case scenario is obtaining one to one copy of original source code since reading and understanding high level code is easiest so will the patching be reality often not possible due various protecting of source code, also unnecessary since lower level representation of source code might be enough to reveal mechanism patch and compile low level code tools and documentation have matured many tools and techniques

gaining information about a program and its implementation details, process aims at enabling an analyst to understand the concrete relation between implementation and functionality, optimal output of such a process would be the original source code of the application, not possible in general

Therefore, it is necessary for such a process to provide on the one hand abstract in-

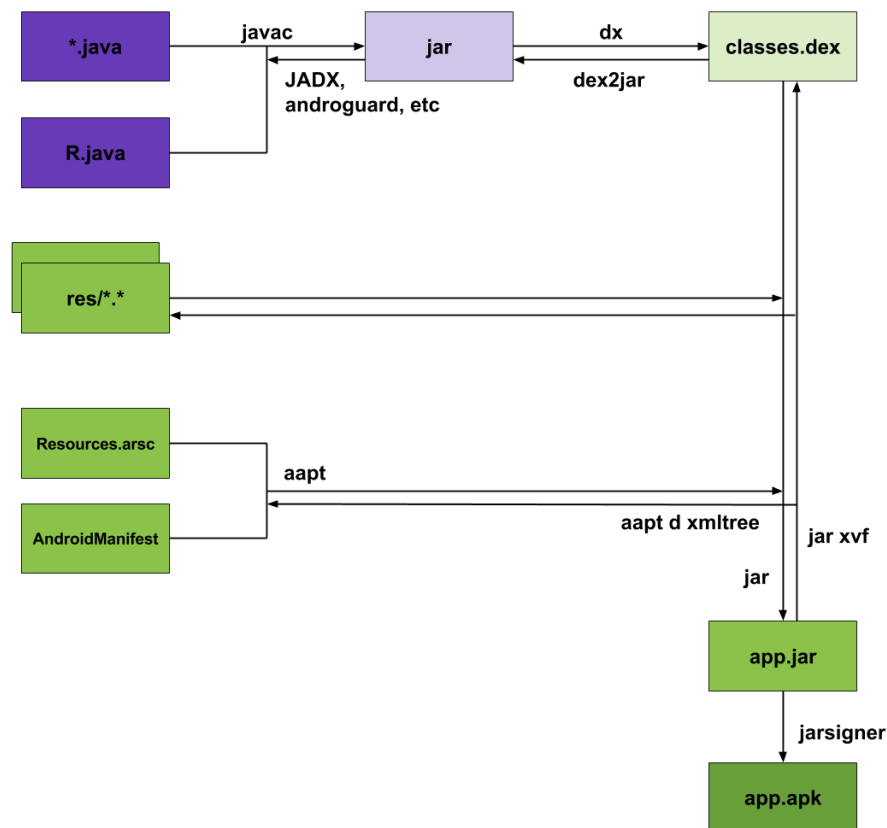


Figure 2.16: Overview of build and reverse engineering of an APK [44]

formation about structure and inter-dependencies and on the other hand result in very detailed information like bytecode and mnemonics that allow interpretation of implementation

hoffentlich starting points für investigations

java, e.g. read the program code faster

was ist reengineering? wie funktioniert es? was ist das ziel?

reverse engineering process makes use of a whole range of different analysis methodologies and tools.

only consider static analysis tools

IN ORDER TO GET FULL OVERVIEW DEX/SMALI/JAVA -see- WARUM?

WAS MACHEN DIE TOOLS IM ALLGEMEINEN? WOZU BENUTZEN WIR SIE?

- It comes as no surprise that .dex and .class are isomorphic
- DEX debug items map DEX offsets to Java line numbers
- Dex2jar tool can easily “decompile” from .dex back to a .jar
- Extremely useful for reverse engineering – Even more useful for malice and mischief

- Flow from DEX to JAVA is bidirectional, meaning that an attacker can:
- Decompile your code back to Java
- Remove annoyances like ads, registration
- Uncover sensitive data (app logic, or poorly guarded secrets)
- Replace certain classes with others, potentially malicious ones
- Recompile back to JAR, then DEX
- Put cloned/trojaned version of your app on Play or another market
- ASEC/OBB “solutions” for this fail miserably when target device is rooted.

<https://mobilesecuritywiki.com/>

https://net.cs.uni-bonn.de/fileadmin/user_upload/plohmann/2012-Schulz-Code_Protection_in_Android.pdf

main tools

2.4.1 Retrieving an APK

5 most apps are installed /data/app, android restricts access, with root possible

to get installed applications on phone use android package manager after connecting phone to computer and having ADB tools installed adb shell pm list packages -f(1) outputs a list of installed apps in format <namespace>.<appName> and an appended number "-1", each is a folder of installed app containing a base.apk (the application apk) example 2 enthält return von (1)

then find app which should be transferred to computer and use adb pull /data/app/me.neutze.licensetest1/base.apk to download app into current folder

in case you have root you can use file manager as solid explorer to access the folder directly and copy apk to user-defined location/send per mail

[47]

In the following there will be an example application to generalise the procedure. The application is called LicenseTest and has for our purpose a license verification library included (Amazon, Google or Samsung).

In order to analyse an APK, it has to be pulled from the Android device onto the computer. First the package name of the app has to be found out. This can be done by using the ADB. Entering example 1 returned example 2

dann auf verschiedenen levels anschauen mit den folgenden tools

2.4.2 dex Analysis

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nur dex weil die apps im moment so vorliegen

aosp-supplied dexdumo to disassemble dex

[44] always attack dex since the protection mechanism is in there (except JNI?) since apk is zip like decompression tool like 7zip can extract classes.dex from apk file

hexdump to get bytecode

code wie er vorliegt, wenn was geändert wird wird es hier geändert

SCRIPT (LISTING BENUTZEN UND RICHTIGE APP) RESULT OUTPUT dex hex-

```
1 #!/bin/bash
2 #hexdump dex
3 unzip lvttest-version.apk -d /tmp/
4 hexdump -C /tmp/classes.dex >> /dex/version/classes.txt
```

Code Snippet 2.7: Script to extract the .dex byte code from the APK

dump, start of the dex file, e.g first 8 byte represent the dex header magic dex.035, version 35[11] LINE | bytecode | ASCII representation

```
00000000 64 65 78 0a 30 33 35 00 ae a5 51 7e 06 f7 00 84 |dex.035...Q~....|
00000010 ee 23 5d 3b 4a 61 bb 08 51 a7 c9 02 c1 4e d2 91 |.#];Ja..Q....N..|
00000020 0c fb 21 00 70 00 00 00 78 56 34 12 00 00 00 00 |...!.p...xV4....|
00000030 00 00 00 00 ac 88 06 00 f4 4e 00 00 70 00 00 00 |.....N..p...|
00000040 ad 09 00 00 40 3c 01 00 0a 0e 00 00 f4 62 01 00 |....@<.....b..|
00000050 3d 27 00 00 6c 0b 02 00 ff 4b 00 00 54 45 03 00 |='.1...K..TE..|
```

Code Snippet 2.8: dex hexdump example

jedes tool:

woher kommt es?

wozu wurde es erfunden?

wer hat es erfunden? quelle

blabla von der seite

wozu benutze ich es?

welches abstrahierungslevel

beispiel

additional features?

WARUM SCHAUEN WIR ES UNS AN?

wo findet man es?
welches level?
vorteil
blabla aus dem internet

2.4.3 Smali Analysis

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basically jasmin syntax smali, most popular Dalvik bytecode decompilers (used by multiple reverse engineering tools as a base disassembler, amongst which is the also well-known apktool) [41]

stichwort mnemonics, eine seite dex und auf der anderen seite smali, dex bytecode vs smali, Only a few pieces of information are usually not included like the addresses of instructions

unintuitive representation, deswegen smali mit corresponding mnemonics

mnemonics and vice versa is available due to the bijective mapping

correct startaddress and offset can be challenging. There are two major approaches: linear sweep disassembling and recursive traversal disassembling, The linear sweep algorithm is prone to producing wrong mnemonics e.g. when a assembler inlines data so that instructions and data are interleaved. The recursive traversal algorithm is not prone to this but can be attacked by obfuscation techniques like junkbyte insertion as discussed in section 4.4. So for obfuscation, a valuable attack vector on disassembling is to attack the address finding step of these algorithms

<https://github.com/JesusFreke/smali>

Smali code is the generated by disassembling Dalvik bytecode using baksmali. The result is a human-readable, assembler-like code

The smali [7] program is an assemblerhas own disassembler called "baksmali"

can be used to unpack, modify, and repack Android applications

interesting part for obfuscation and reverse engineering is baksmali. baksmali is similar to dexdump but uses a recursive traversal approach to find instructions

vorteil? -see- So in this approach the next instruction will be expected at the address where the current instruction can jump to, e.g. for the "goto" instruction. This minimizes some problems connected to the linear sweep approach. baksmali is also used by other reverse engineering tools as a basic disassembler

RESULT OUTPUT: selbe wie dex, jedoch human readable, no big difference, nebeneinanderstellung dex/smali

SCRIPT (LISTING BENUTZEN UND RICHTIGE APP)

```
1 #!/bin/bash
2 #baksmali
3 java -jar baksmali.jar -x lvltest-version.apk -o /baksmali/version/
```

Code Snippet 2.9: Script to generate the corresponding smali code for a given APK

```
.method protected onDestroy()V
    .registers 2

    .prologue
    .line 77
    invoke-super {p0}, Landroid/support/v7/app/CompatActivity;->onDestroy()V

    .line 78
    iget-object v0, p0, Lme/neutze/licensetest/MainActivity;->mChecker:Lcom/google/android/
        vending/licensing/LicenseChecker;

    invoke-virtual {v0}, Lcom/google/android/vending/licensing/LicenseChecker;->onDestroy()V

    .line 79
    return-void
.end method
```

Code Snippet 2.10: smali example

EXAMPLE BESCHREIBEN code snippet 2.10

jedes tool:
woher kommt es?
wozu wurde es erfunden?
wer hat es erfunden? quelle
blabla von der seite
wozu benutze ich es?
welches abstrahierungslevel
beispiel
additional features?
WARUM SCHAUEN WIR ES UNS AN?
wo findet man es?
welches level?
vorteil

blabla aus dem internet

2.4.4 Java Analysis

This is my real text! Rest might be copied or not be checked!

dex different patterns for mobile Usage, java does not really now, thats why different java decompiler

probleme des disassemblers erklären

interpretations sache

deswegen zwei compiler

unterschiedliche interpretation resultiert in flow und auch ob sies können ist unterschiedlich

ectl unterschiede/vor-nachteile

ggf bezug zu DALVIK/buildprocess (Java wird disassembled und dann assembler)

androguard

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An analysis and disassembling tool processing both Dalvik bytecode and optimized bytecode

DAD which is also the fastest due to the fact it is a native decompiler, WAS ist dad? ERKLÄREN? .dex files was performed with DAD, the default disassembler in the androguard analysis tool, largest successful disassembly ratio

underlying algorithm is recursive traversal

androguard has a large online open-source database with known malware patterns [41]

<https://github.com/androguard/androguard>

powerful analysis tool is Androguard

includes a disassembler and other analysis methods to gather information about a program

Androguard helps an analyst to get a good overview by providing call graphs and an interactive interface -see- habe nur CLI benutzt

The integrated disassembler also uses the recursive traversal approach for finding instructions like baksmali, see section 2.2

one most popular analysis toolkits for Android applications due to its big code base

and offered analysis methods -see- quelle, warum

RESULT OUTPUT code Listing

SCRIPT (LISTING BENUTZEN UND RICHTIGE APP)

SCRIPT (LISTING BENUTZEN UND RICHTIGE APP)

```
1 #!/bin/bash
2 #androguard
3 python androdd.py -i lvltest-version.apk -o /androguard/version/
```

Code Snippet 2.11: Script to decompile to Java using androguard

```
private void doCheck()
{
    this.mCheckLicenseButton.setEnabled(0);
    this.setProgressIndicatorIndeterminateVisibility(1);
    this.mStatusText.setText(2131099673);
    this.mChecker.checkAccess(this.mLicenseCheckerCallback);
    return;
}
```

Code Snippet 2.12: Java code example using androguard

EXAMPLE BESCHREIBEN code snippet 2.12

jedes tool:

woher kommt es?

wozu wurde es erfunden?

wer hat es erfunden? quelle

blabla von der seite

wozu benutze ich es?

welches abstrahierungslevel

beispiel

additional features?

WARUM SCHAUEN WIR ES UNS AN?

wo findet man es?

welches level?

vorteil

blabla aus dem internet

JADX

This is my real text! Rest might be copied or not be checked!

RESULT OUTPUT code Listing

SCRIPT (LISTING BENUTZEN UND RICHTIGE APP)

```
1 #!/bin/bash
2 #jadx
3 jadx -d /jadx/version/ --deobf --show-bad-code lvltest-version.apk
```

Code Snippet 2.13: Script to decompile to Java using JADX

```
private void doCheck() {
    this.mCheckLicenseButton.setEnabled(false);
    setProgressBarIndeterminateVisibility(true);
    this.mStatusText.setText(C0213R.string.checking_license);
    this.mChecker.checkAccess(this.mLicenseCheckerCallback);
}
```

Code Snippet 2.14: Java code example using JADX

EXAMPLE BESCHREIBEN code snippet 2.14

<https://github.com/skylot/jadx>

jedes tool:

woher kommt es?

wozu wurde es erfunden?

wer hat es erfunden? quelle

blabla von der seite

wozu benutze ich es?

welches abstrahierungslevel

beispiel

additional features?

WARUM SCHAUEN WIR ES UNS AN?

wo findet man es?

welches level?

vorteil

blabla aus dem internet

Es gibt noch mehr tools, wurden angewendet und verglichen, aber diese waren die haupttools und haben ihren dienst erfüllt

2.4.5 Detect Code Manipulations

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vergleich gibts guten einblick was geändert wurde und wie es auf dem gegebenem lvl funtkioniert

vergleich von original und modifizierten code einer apk auf einer code ebene
needed to see differences before and after cracking tool

diff is used

```
1 #!/bin/bash
2 #dex
3 diff -Naur /dex/original/ /dex/manipulated/ > dex.diff
4 #smali
5 diff -Naur /baksmali/original/ /baksmali/manipulated/ > baksmali.diff
6 #jadx
7 diff -Naur /jadx/original/ /androguard/jadx/ > jadx.diff
8 #androguard
9 diff -Naur /androguard/original/ /androguard/manipulated/ > andro.diff
```

Code Snippet 2.15: Script to compare the original and manipulated APK to see the modifications in the different presentations

erklärung command [65] -N: Treat absent files as empty; Allows the patch create and remove files.

-a: Treat all files as text; Allows the patch update non-text (aka: binary) files.

-u: Set the default 3 lines of unified context; This generates useful time stamps and context.

-r: Recursively compare any subdirectories found; Allows the patch to update subdirectories.

script erklären

RESULT code snippet 3.1

wo findet man es?

welches level?

vorteil

blabla aus dem internet

3 Cracking Android Applications with LuckyPatcher

Cracking apps are a widespread phenomenon on Android these days. There are a number of applications which try to attack and alter Android apps. This piracy thread is discussed a lot in the Android developer community. This thesis focuses on the popular cracking app called LuckyPatcher, especially on its license verification bypassing mechanism.

3.1 LuckyPatcher

reason lucky patcher is taken extremely popular and easy (no technical knowledge except root but apps can be traded)

main goal is to circumvent license verification, app should behave as it is legally acquired in app store, by user hence work normally, full features

most common way client-server license verification, app gathers info and sends to server, server checks info and depending on this sends response, finally app acts according to response code

since server is not accessible and man-in-the-middle has to break encryption, like spoofing, which is difficult (encryption in general), has to work in application

effective, popular, vielseitig (viel internet -see- quelle) high damage potential since popular, automated and general use by non professional

[47]

written by ChelpuS

for this master's thesis the version 5.9.5 written by chelphus requires root and busybox, an application which provides standard UNIX tools for Android[61] apply patches: - Remove license check in premium apps (used to crack DRM) - remove ads -Customize and restrict permissions and activities -Create a modified app (means an APK file to install the app with a patch already applied)

not 100percent warranty that patching works due to modified libraries

erklären wie man ihn getestet hat, woher die apps, nachgefragt ob ok etc

LuckyPatcher is described as following on the official webpage: "Lucky Patcher is a great Android tool to remove ads, modify apps permissions, backup and restore apps,

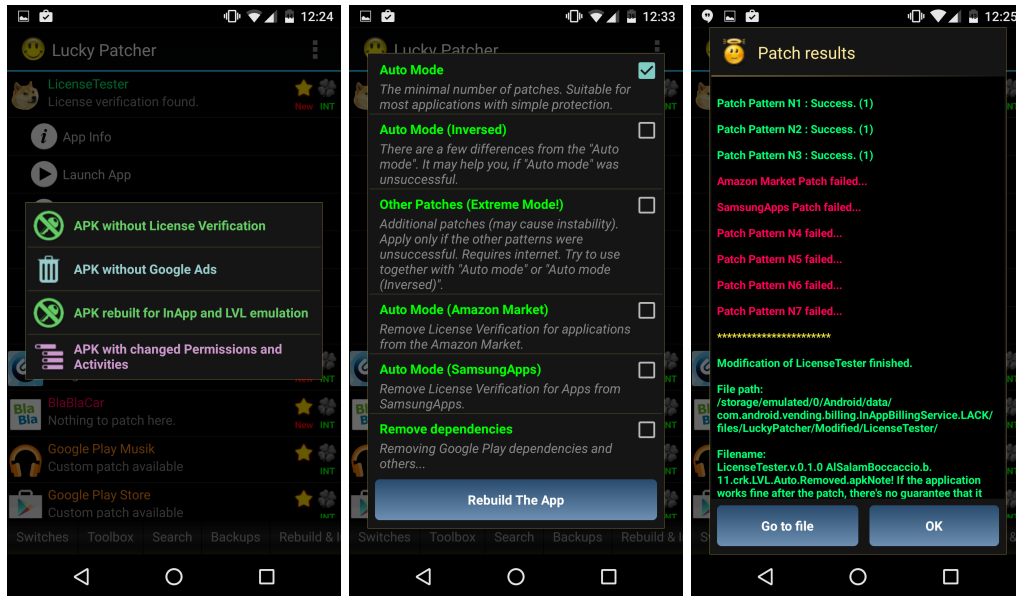


Figure 3.1: c

Left: Features offered LuckyPatcher Middle: Variants to crack license verification Right: Result after patching

bypass premium applications license verification, and more. To use all features, you need a rooted device." [26]

install apk from playstore -see- have root -see- open lucky -see- chose mode

this thesis focuses on the removing of licensing check, angewendet auf verschiedene apps aus den jeweiligen stores

3.2 Code Manipulation

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analysis done by looking at patched applications since luckypatcher has done a lot of obfuscation etc which makes it almost impossible to understand (tools crash, junkbyte injection, only a few giant classes in java which do not make sense, some classes not decompiled since crash, dex/smali not very useful since no names etc), poor decompilation result hard to analyze since of obfuscation and anti-decompilation measure

so look at cracked application in order to understand how lucky apptcher works diff between code of unpatched and patched version of application which have lvl included first it was tested with a simple app which was created and implemented lvl also for

apps from app store to see behaviour diff tool to compare code base and see positions
lucky patcher attacks

multiple tools used to reverse engineer the license verification circumvention by lucky patcher (see tools from reengineering) first look at java code (higher representation, human readable), to understand what/where class/function have been modified smali for having names for the bytecode executions dex to see exactly how it was modified document intended change by luckypatcher

luckypatcher works by patching dex (patching based not call intercept)

most patching options target googles lvl, but also available for amazon and samsung information if lvl is contained can be pulled from manifest because of com.android.vending.CHECK_LICENSE permission, only to show user and can circumvent anyway since solely for user to flag in market (ist das noch so?), trying to trick and not declare would break violate permissions and be stopped by android

luckypatcher extracts original classes.dex from apk and patches it patching is done on binary level and done by using different patterns which are dependent on the modus (see patterns/modi) the result is either used to substitute the optimized classes.dex of attacked app with the patched .odex in dalvik cache (/data/dalvik-cache/), or can be output as an apk

works on most applications but has few problems on custom modified lvl libraries (liste der apps wo es funzt aus gdrive tabelle)

after applying patterns LP needs to update file header to reflect new checksum and hash values

[47]

wo arbeitet er?

warum dex und nicht odex anschauen?

Since the code is modified directly a static analysis is sufficient.

UM ES EINFACHER ZU MACHEN, KEINE ODEX (WARUM), APK CREATEN UND AUF EINEM NORMALEN HANDY INSTALLIEREN(dann sieht man dass man die app wem anders gecracked geben kann - ringschluss blackmarket)

after modification the dex is signed again in order to work on the phone (see installation und signature)

WIE IST MEIN VORGEHEN? aufgrund dass odex dateien device spezifisch sind und allgemeiner ansatz gesucht wird, wird die app playstore -> modified APK erstellen -> analysieren

3.3 Cracking License Verification

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patterns und patching modes grob erklären (modi von luckypatcher die verschiedene operationen (pattern) auf app anwenden) => vorgehensweise zur

see figure 3.1 middle liuckypatcher offeres different sets of methods to remove the license verification Auto Mode - "The monomal number of patches. Suitable for most applications with simple protection" - uses patterns

Auto Mode (Inversed) - "There are a few differences from the "Auto mode". It may help you, if "Auto mode" was unsuccessful." - uses patterns

Other Patches (Extreme Mode!) - "Additional patches (mnay cause instability). Apply only if the other patterns were unsuccessful. Requires internet. Try to use together with "Auto mode" or "Auto mode (Inversed)"." - uses patterns

Auto Mode (Amazon Market) - "Removes License Verification for applciations from Amazon Market" - uses patterns

Auto Mode (SamsungApps) - "Removes License Verification for Apps from SamsungApps" - uses patterns (is now GalaxyApps)

in order to find out what patterns are doing, different apps had to be analysed after patching the apps chosen were already owned, in addition an app for each license verification model was created, uploaded and installed from the store so the license verification was working

to verify that license check is enabled, each app was extracted from the device using method described in 2.4.1 and installed on a device with a different google account then for each app a modified apk see figure 3.1 left, using one modus is created and copied to a computer for further inspection. so for each app there are 5 modified apks now

as example apps to show results Runtastic Pro[51], Version 6.3, the created LicenseTest and Teamspeak 3[62], Version 3.0.20.2, are chosen

the result after patching the different apps with each modus returned the patterns used by each modus

3.4 Patching Patterns

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In order to identify the single patterns, the information from the output of cracking 3.1 right, of the apps was matched with the changes in the code. the changes in the code were inspected on dex, smali and java level with the tools explained in Section 2.4.

Modus	Application		
	LicenseTester	Runtastic Pro	Teamspeak 3
Purchased	yes	yes	yes
Pirated	no	no	no
Auto	yes	yes	no
Auto (Inversed)	no	yes	no
Extreme	no	yes	no
Auto+Extreme	yes	yes	no
Auto (Inversed)+Extreme	no	yes	no

Table 3.1: Functionality for the test apps before and after patching

in case of LVL, from the information where in the package the change was done, conclusion to the original class from in the lvl could be done

diff for original app and modified app

example code taken from an app which was inspected, modification happens for all at the same spot/manner

dex == smali, smali better readable but dex to see how easy change since the translation from java to dex does some optimizations/logik, dex and java do not express the same, but it is how it is in the decompiled code, java is also an abstraction of the actual code, sometimes java also a little confusing since changes happened in dex code and cannot be decompiled to java in a good manner, very messy, it is included for better understanding anyways since humanreadable

The names of the patterns/patches are taken from the patching result output figure 3.1 on the right

Patch Pattern N1

classes it attacks com/google/android/vending/licensing/LicenseValidator LicenseValidator, responsible for decrypting and verifying the response from the licensing server[13]

```
@@ Pattern N1 @@
- 03 01 00 00 0f 00 00 00 1a 00 00 00 0f 00 00 00 |.....|
+ 03 01 00 00 0f 00 00 00 0f 00 00 00 1a 00 00 00 |.....|
```

Code Snippet 3.1: Diff on Dex level for N1 pattern

values are swapped

```
@@ Pattern N1 @@
```

```
- 0x1 -> :sswitch_e0
- 0x2 -> :sswitch_d5
+ 0x1 -> :sswitch_d5
+ 0x2 -> :sswitch_e0
```

Code Snippet 3.2: Diff on Smali level for N1 pattern

switch case for input 0x01 (not licensed) and 0x02 (old license key) are swapped

```
@@ Pattern N1 @@
- case LICENSED_OLD_KEY: handleResponse();
- case NOT_LICENSED: handleError();
+ case NOT_LICENSED: handleResponse();
+ case LICENSED_OLD_KEY: handleError();
```

Code Snippet 3.3: Diff on Java level for N1 pattern (abstracted)

old code when license code not licensed return in case not licensed with error after patching when not licensed return as old license key

Patch Pattern N2

classes it attacks com/google/android/vending/licensing/LicenseValidator.java LicenseValidator, responsible for decrypting and verifying the response from the licensing server[13] greift auch zB. google maps api (com/google/android/gms/) oder in app billing (com/android/iab/v3/) an, collateral schaden one Pattern

```
@@ Pattern N2 @@
- 0c 05 6e 20 9d 4a 53 00 0a 05 39 05 2d 00 1a 05 |..n .JS...9.-...|
+ 0c 05 6e 20 9d 4a 53 00 12 15 39 05 2d 00 1a 05 |..n .JS...9.-...|
```

Code Snippet 3.4: Diff on Dex level for N2 pattern

move-result is replaced by move const

```
@@ Pattern N2 @@
- move-result v5
+ const/4 v5, 0x1
```

Code Snippet 3.5: Diff on Smali level for n2 pattern

instead of moving the result from a function to v3, it is initiated with true/1

```
@@ Pattern N2 @@
- if (sig.verify(Base64.decode(signature))) {...;}
```

```
+ sig.verify(Base64.decode(signature); ...;
```

Code Snippet 3.6: Diff on Java level for N2 pattern (abstracted)

old code: signature was verified, if true it is continued after patching the verification is treated as always true and so it is continued

Patch Pattern N3

classes it attacks com/google/android/vending/licensing/APKExpansionPolicy.java com/google/android/vending/licensing/ServerManagedPolicy.java Policy integration of License Verification Library, those are the two examples offered by Google[13]

```
@@ Pattern N3 @@
- 12 10 12 01 71 00 a6 89 00 00 0b 02 52 84 c1 1c |....q.....R...|
+ 12 10 12 11 71 00 a6 89 00 00 0b 02 52 84 c1 1c |....q.....R...|

@@ Pattern N3i @@
- 34 00 00 00 12 11 12 00 71 00 70 9d 00 00 0b 02 |4.....q.p.....|
+ 34 00 00 00 12 01 12 00 71 00 70 9d 00 00 0b 02 |4.....q.p.....|
```

Code Snippet 3.7: Diff on Dex level for N3 pattern

for forward value 0x0 is switched with 0x1 and for inverse...inversed

```
@@ Pattern N3 @@
- const/4 v1, 0x0
+ const/4 v1, 0x1

@@ Pattern N3i @@
- const/4 v1, 0x1
+ const/4 v1, 0x0
```

Code Snippet 3.8: Diff on Smali level for N3 pattern

variable is initiated with opposite of what they were initiated before

```
@@ Pattern N3 @@
- return false;
+ return true;

@@ Pattern N3i @@
- return true;
+ return false;
```

Code Snippet 3.9: Diff on Java level for N3 pattern (abstracted)

old code variable is initiated false and true for inversed as basic return value after patching the return is the opposite, meaning all true results are now false and all false are now true, meaning wrong input is declared as OK

Patch Pattern N4

classes it attacks com/google/android/vending/licensing/LicenseChecker.java LicenseChecker, class that instatiates a license check[13]

```
@@ Pattern N4 @@
- d5 70 00 00 0a 00 38 00 0e 00 1a 00 5a 20 1a 01 |.p....8....Z ..|
+ d5 70 00 00 0a 00 33 00 0e 00 1a 00 5a 20 1a 01 |.p....3....Z ..|
```

Code Snippet 3.10: Diff on Dex level for N4 patch

if-eqz is repalces by if-ne

```
@@ Pattern N4 @@
- if-eqz v0, :cond_15
+ if-ne v0, v0, :cond_15
```

Code Snippet 3.11: Diff on Smali level for N4 patch

in the original code variable v0 is compared for not equality with zero after it is patched it is always compared with itself which returns always true and the condition is always called

```
@@ Pattern N4 @@
- if(licenseCached()) {...}
+ b = licenseCached();
+ if(b == b) {...}
```

Code Snippet 3.12: Diff on Java level for N4 patch (abstracted)

in the original code it is checked whether the license is already cached, fi yes, condition is called after patching the result of the check is always compared to itself, and thus the condition is always called

Patch Pattern N5

classes it attacks com/google/android/vending/licensing/LicenseValidator.java

works the same way as pattern N2

im gegensatz zu N2 wird jetzt die condition nie aufgerufen anstatt sie immer aufzurufen wie in N5 result is that the check for the result code given to the function and extracted from the server response is disabled since the result of the check is set to always false

Patch Pattern N6

classes it attacks com/google/android/vending/licensing/LicenseValidator.java

```
@@ Pattern N6 @@
- 38 0a 06 00 32 4a 04 00 33 5a 21 01 1a 00 ab 15 |8...2J..3Z!.....|
+ 12 0a 00 00 32 00 04 00 33 5a 21 01 1a 00 ab 15 |...2...3Z!.....|
```

Code Snippet 3.13: Diff on Dex level for N6 patch

if-eqz is replaced by move constant, variables for if-eq are changed

```
@@ Pattern N6 @@
- if-eqz p2, :cond_e
+ const/4 p2, 0x0

- if-eq p2, v4, :cond_e
+ nop
+
+ if-eq v0, v0, :cond_e
```

Code Snippet 3.14: Diff on Smali level for N6 patch

instead of testing for zero and then calling a condition, the to test variable is changed and the condition removed the second equal check is done by comparing a variable with itself thus always true and the condition is called

```
@@ Pattern N6 @@
- if (p2 == 0 || p2 == v8) {...}
+ p2 = 0;
+ if (v0 == v0) {...}
```

Code Snippet 3.15: Diff on Java level for N6 patch (abstracted)

instead checking two variables for a case, the condition is just always called

Patch Pattern N7

classes it attacks com/google/android/vending/licensing/ILicenseResultListener.
java ILicenseResultListener, IPC callback implementation, receives async response
from server[13] einfach auf alles was in com/android/ ist, some kind of bruteforce
similar to N2, but Java result is more generic

```
@@ Pattern N7 @@  
- x = foo();  
+ x = false;
```

Code Snippet 3.16: Diff on Java level for N7 patch (abstracted)

instead of initializing variable with result from function, it is always initialized with
false / 0

Amazon Market Patch

also applies pattern N2

classes it attacks com/amazon/android/licensing/b.java com/amazon/android/o/d.
java
see, obfuscated
similar like pattern N4

```
@@ Pattern A @@  
- 0a 00 38 00 0a 00 62 00 56 20 1a 01 4e 49 6e 20 |..8...b.V ..NIn |  
+ 0a 00 33 00 0a 00 62 00 56 20 1a 01 4e 49 6e 20 |..3...b.V ..NIn |
```

Code Snippet 3.17: Diff on Dex level for Amazon patch

if-eqz is repalces by if-ne

```
@@ Pattern A @@  
- if-eqz v0, :cond_1f  
+ if-ne v0, v0, :cond_1f
```

Code Snippet 3.18: Diff on Smali level for Amazon patch

in the original code variable v0 is compared for not equality with zero after it is patched
it is always compared with itself which returns always true and the condition is always
called

```
@@ Pattern A @@  
- if(v0.equals("LICENSED")) {...}  
+ b = v0.equals("LICENSED")
```

```
+ if(b == b) {...}
```

Code Snippet 3.19: Diff on Java level for Amazon patch (abstracted)

in the original code the result from the server is tested whether it is "LICENSED" after patching the response is always evalauted and the result is compared with itself which is always true

result never the less what the check for "LICENSED" returns, the condition for "LICENSED" is always called

Samsung Market Patch

also applies pattern N2

classes it attacks com/samsung/zirconia/LicenseRetriever.java com/samsung/zirconia/Zirconia.java

not obfuscated

two patterns, lets call it S1 and S2, S1 used on both, S2 used twice on zirconia

```
@@ Pattern S1 @@
- 08 00 0c 08 6e 10 66 4a 08 00 0a 06 32 d6 0a 00 |....n.fJ....2...|
+ 08 00 0c 08 6e 10 66 4a 08 00 0a 06 32 00 0a 00 |....n.fJ....2...|

@@ Pattern S2 @@
- 10 02 0a 00 0f 00 00 00 03 00 01 00 02 00 00 00 |.....|
+ 10 02 12 10 0f 00 00 00 03 00 01 00 02 00 00 00 |.....|
```

Code Snippet 3.20: Diff on Dex level for Samsung patch

S1 input for if-eq is modified S2 move-result is replaced by move const

```
@@ Pattern S1 @@
- if-eq v6, v13, :cond_52
+ if-eq v0, v0, :cond_52

@@ Pattern S2 @@
- move-result v0
+ const/4 v0, 0x1
```

Code Snippet 3.21: Diff on Smali level for Samsung patch

S1 in the original code checks whether to different variables are equal after patching the check is done with the same variables and thus always returns true

S3 in the original code the result of a function is moved to v0 and returned after patching true/1 is always moved to v0 and returned


```

@@ Pattern S1 @@
- if (v6 == 12) {...}
+ if (v0 == v0) {...}

@@ Pattern S2 @@
- return foo();
+ return 1;

```

Code Snippet 3.22: Diff on Java level for Samsung patch (abstracted)

com/samsung/zirconia/LicenseRetriever.java always starts condition, even though input is not "12" as supposed to start com/samsung/zirconia/Zirconia.java S1 always returns true for checkLicenseFile and checkLicenseFilePhase2, does not check anything which is done normally S2 always starts condition, even though input is not as supposed to start com/samsung/zirconia/Zirconia.java

Modus	Patterns							
	N1	n3	N3	N3i	N4	N5	N6	N7
Auto	X	X	X		X			
Auto (Inversed)	X	X		X	X			
Extreme						X	X	X
Auto+Extreme	X	X	X		X	X	X	X
Auto (Inversed)+Extreme	X	X		X	X	X	X	

Table 3.2: Overview of License Verification Library patching patterns applied by each modus

summarizing what patterns each modus applies Table 3.2

auto: just applies minimum patches, N1 swaps switch cases so not licensed is treated here as old license key in the LicenseValidator, N2 skips the signature verification in the LicenseValidator, N3 inverts the return boolean for the policy checks in the implemented Policy class by initializing with 0/false, and N4 skips, in the only case occurred in the test set, the check whether download is allowed and allows it always auto inverse: does the same as auto but initializes the policy check with 1/true instead of false extreme: auto+extreme: applies auto and extreme patches auto inverse+extreme: applies auto and extreme patches

!!! kann man das excel sheet in die dateien machen und nicht als appendix, da manche apps ihre ergebnisse nicht öffentlich sehen wollen !!!

3.5 Learnings and Conclusion

This is my real text! Rest might be copied or not be checked!

first patching point could be the initial call, in case modified lvl patching initial call would be not enough since the on success block could contain important code (like ui creation) then it would be useless, target on specific points where decisions are made to alter as few code as possible

since automated customizations have to be implemented to trick it make false checks to detect tampering -see- user patch

amazon/samsung not much to do since from company, beyond control of developer since injection after developer and a library provided by samsung which is only called, that is why the following not simple methods target lvl

known bytecode patterns, replace with custom, makes mechanism useless

following present ways of protecting against patching attempts, especially predefined recipes circumventing the LVL high motivation, the patterns/patching modes cover many apps, more than custom

should not use one but many methods solution for current version of lucky patcher, future might be different, arms race scenario [47]

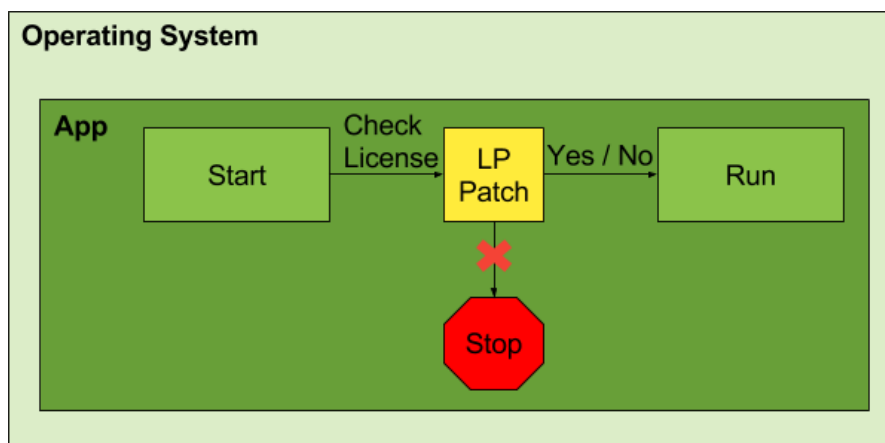


Figure 3.2: Abstraction of the current attack on the license verification mechanism

nur ja/nein test bzw ergebnis zuweisung und drauf folgender test kann IMMER geskippt werden, vergleich figure 2.14

fügt keinen code hinzu sondern ersetzt commands => checksum/signature

4 Counter Measurements for Developers

um sich davor zu schützen müssen entwickler gegenmaßnahmen unternehmen

4.1 Extend Current Library

den test itself schwerer zu cracken siehe angriff figure 3.2

techniken entwickeln damit der automatische patching mode von luckypatcher nicht mehr funktioniert ansatz figure 2.14 element (1) zu verändern damit automatisch fehlschlägt

4.1.1 Modifications on the Google LVL

This is my real text! Rest might be copied or not be checked! warum ändern? suggested by google

boy ()

applied when programming

way to challenge luckypatcher is to actively go against luckypatcher patterns, achieved by modifying the library, see patterns to fight in patterns chapter can be done in different ways, modify library or go native

many developers do not customize the library, easy to hack [47]

goal is to make lvl implementation unique, difficult to trace when decompiled counter intuitive from traditional software engineering viewpoint, removing functions, hiding license check routines in unrelated code

Google is aware of easy hacking and thus suggests modifications to the lvl modify license verification library in way that it is difficult for attacker to modify the disassembled code and get a positive check as result advantages, harder to crack, cannot be used as blueprint and no blueprint can be used on it, unique [38] ERWÄHNEN DASS IM PROGRAMMIER PROZESS IMPLEMENTIERT

this should be the first solution anyone does in order to actively fight luckypatcher automatischen angriff aushebenln indem andere struktur

Modify the Library

This is my real text! Rest might be copied or not be checked!

STRUKTUR ÄNDERN CODE ISOMORPH ÄNDERN. e.g. switch zu if figure 2.14 element (1)

most developers include the LVL unchanged without modifying it, attacks can always be done the same way so this is very easy for luckypatcher for own security and the security of other developers try to create a unique implementation, ideal would be that no patterns can be applied to you and that in case the implementation gets racked no pattern of yours can be applied to others

this is a list of ideas of how to modify versus each pattern,

pattern 1,7 attacks the switch, the idea is to replace the switch with an if statement or shuffle the cases move it to a function and implement it somewhere as well thus the code might no longer be together with the rest of the class and the attacker has to specific search for it

pattern 2,4,5 skips using the outcome of a function and setting it always to true, this is a bit harder since it is already in a function, fitting bulk code around can make it harder to detect, especially for patterns, also checking inside again can help with detecting whether the function is tampered, in case it is tampered the app can be killed or elements could not be loaded

pattern 3 modifies the return values on initialization, idea to alter the return value, changing it to e.g. int, thus all the ifs have to be modified to fit the needs

general ideas move the lvl into own application folder replace functions with inline code when possible test again inside the function and e.g. kill the app on tampering best would be to really make it different, e.g. recreate classes

creativity helps, does not protect at all but when applied correct automode does not work and patterns have to be registered

this tries to directly encounter luckypatcher by fighting the way the patterns work

it is easy to apply and there are no limits of variants how it can be modified luckypatcher has to look at each app individual and in the worst case create custom patches but as it seems developers do not like to modify as seen in analysis since all apps are somehow patchable

Native Implementation

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luckypatcher automatic patching works on dex, why not remove the key license verification code from java and move it to native code, this way luckypatcher has to create a custom recipe for your application since custom recipes can inject .so files

native code can be executed using two things, android ndk a toolset to implement native-code languages, e.g. c or c++, and JNI used by java to execute native code

native code is difficult to be decompiled, can be checked for tampering when loading it

elemente für app in native initiieren, damit man nicht einfach deaktivieren kann
nur gut wenn wichtige funktionen der app enthält

at first a good protection against luckypatcher since the automatic patching discussed in chapter 3 does not work for the app any longer, but not protection of luckypatcher because it supports custom patching when analyzing luckypatcher there can be .so files be found which are used to replace existing ones in order to patch functionality

so now attackers have to invest time in analyzing the native code difficult since in opposite of byte-code, it does not contain a lot of meta-data such as local variable types, class structure, which allows bytecode to be compiled on multiple devices, this information is discarded in native code in the compilation process

there are two scenarios: first scenario developers creates his own version of native implementation unique, but developer has to create it itself, knowledge and skill is needed and time has to be spent if done right, safe and advantage that the attacker has to invest time for this app itself in order to analyze the native code, then find a method to break it and repack it and make it available as custom patch, scares off attackers since a lot of work, have to evaluate whether app is worth it so if the resources are available, best method

second scenario one public native library provided by google but when all use the same library, it is a vulnerable point because it makes sense for attackers to analyze the library and try to come up with a patch, since one solution can be applied to many different apps which would justify a lot of work as described in the first scenario, this patch then can then be applied as a custom patch via luckypatcher

for this reason when coming up with a native implementation for a library for all, two things should be included - users do not customize library so a heavy obfuscation should be applied - since there is only one version, make it as hard to reengineer and predictable as possible, use encryption and dynamic code generation, automatically customize itself for every app and every time its loaded this needs a lot of research, work and if it would be so simple, big companies like google would already have come up with it, but in this direction it has to go when stick around for a long time with dex and its vulnerabilities

4.1.2 Tampering Protection

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add additional test, have to be cracked as well, first attacker has to realize them and find them

applied when programming

Environment and Integrity Checks, wenn die umgebung falsch ist, kann die app verändert werden. deswegen von vornherein ausschließen, dass die bedingungen dafür gegeben sind. [47]

mechanisms should work for amazon/lvl/samsung –see- beweis! (amazon die signature den die seite vorgibt?)

force close im falle von falschem outcome, entspricht nicht android qualität <http://developer.android.com/distribute/essentials/quality/core.html> aber so wird es dem user klarer dass seine application gecracked ist. harmlosere variante dialog anzeigen oder element nicht laden.

es gibt verschieden punkte um die integrity der application sicherzustellen. dies beinhaltet die umgebung debugg oder rootzugriff, die suche nach feindliche installierte applicationen oder checks nach der rechtmäßigen installation und rechtmäßigen code.

also works for samsung and amazon

in order to remove/disable lvl they have to modify the code unless done precisely can be detected by code [38]

automatischen angriff aushebenln indem andere unbekannte tests die erst entdeckt werden müssen

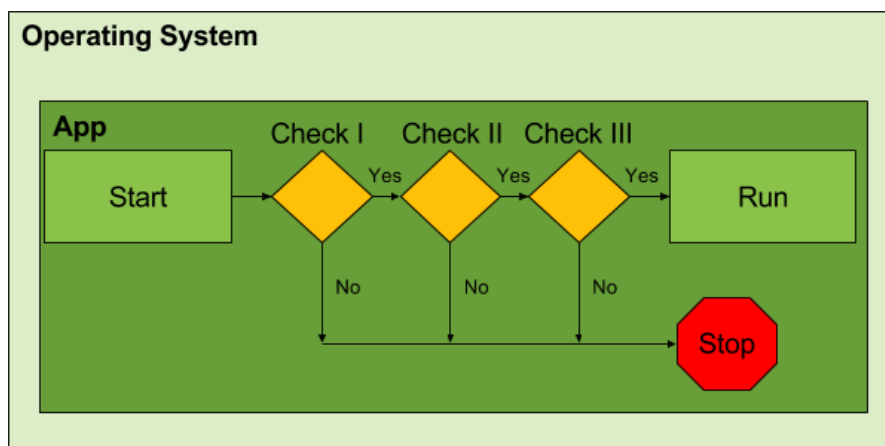


Figure 4.1: Introduction of additional tests to check environment and integrity of the application

all tampering counter measurements have kind of the same pattern, boolean check, simple method == simple fix, can be nulled easily when code is known, just as easy to crack as LVL when you know the code, but attacker has to invest some time to

understand code and to build counter measurement, in addition with Section 4.1.3 this can get annoying, evtl create native versions because harder to crack even though it is simple it adds a little bit extra work to attack and when combined this grows exponential

but be careful because annoy people who want to use root annoy people who bought the app but have luckypatcher/root as well

this does not stop luckypatcher in anyway but it stops the app from working in case the environment is not suitable

but simple method == simple fix just as easy to crack as LVL when you know the code, can be included in custom patch in luckypatcher after analysing the code and unearthing the fitting patterns to crack mechanism can be strengthened by creating native versions since it is not as easy to decompile and analyze as dex

but have to be careful since annoy people who want to use root annoy people who bought the app but have luckypatcher/root as well

extra arbeit für attacker denn er muss die muster auch finden

!!!signature problem mit maps überprüfen!!!

Debuggability

This is my real text! Rest might be copied or not be checked!

WAS IST DIE IDEE DAHINTER? WIE FUNKTIONIERT ES? WIE WIRD ES IMPLEMENTIERT? WIE SIEHT DAS RESULT AUS (EXAMPLE BILD)

der debug modus kann dem angreifer informationen/logs über die application geben während diese läuft, aus diesen informationen können erkenntnisse über die funktionweise geben die für einen angriff/modifikation gewonnen werden können. aus diesen informationen können dann patches für software wie lucky patcher entwickelt werden, da man die anzugreifenden stellen bereits kennt. kann erzwungen werden indem man das debug flag setzt (wo ist es, wie kann es gesetzt werden)

um dies zu verhindern kann gecheckt werden ob dieses flag forciert wird und gegebenenfalls das laufen der application unterbinden

Code SNippet /refcodeSnippet:tamperingDebuggable zeigt eine funktion die auf den debug modus prüft. Dazu werden zuerst in zeile 15 die appinfo auf das debug flag überprüft. ist dieses vorhanden, ist die variable debuggable true. in diesem fall wird dann die geschlossen

```
14 public static boolean isDebuggable(Context context) {
15     boolean debuggable = (0 != (context.getApplicationInfo().flags & ApplicationInfo.
        FLAG_DEBUGGABLE));
16
17     if (debuggable) {
18         android.os.Process.killProcess(android.os.Process.myPid());
19     }
20
21     return debuggable;
22 }
```

Code Snippet 4.1: asd[26]

Root

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WAS IST DIE IDEE DAHINTER? WIE FUNKTIONIERT ES? WIE WIRD ES IMPLEMENTIERT? WIE SIEHT DAS RESULT AUS (EXAMPLE BILD)

<http://stackoverflow.com/questions/10585961/way-to-protect-from-lucky-patcher-play-licen>

SafetyNet provides services for analyzing the configuration of a particular device, to make sure that apps function properly on a particular device and that users have a great experience. <https://developer.android.com/training/safetynet/index.html>
Checking device compatibility with safetynet

Unlocked bootloader doesn't matter. Can't have root installed initially. Has to be a stock / signed ROM. https://www.reddit.com/r/Android/comments/3kly2z/checking_device_compatibility_with_safetynet/

LuckyPatcher

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WAS IST DIE IDEE DAHINTER? WIE FUNKTIONIERT ES? WIE WIRD ES IMPLEMENTIERT? WIE SIEHT DAS RESULT AUS (EXAMPLE BILD)

As the example shows, this check is not only a solution to prevent the application from running when LuckyPatcher is present on the device. The screening can be expanded to check for the installation of any other application, like black market apps or other cracking tools as the code example Code Example 4.3 shows.

<http://stackoverflow.com/questions/13445598/lucky-patcher-how-can-i-protect-from-it>
<http://android-onex.blogspot.de/2015/07/anti-piracy-software-activated-solved>.


```
16 public static boolean findBinary(Context context, final String binaryName) {
17     boolean result = false;
18     String[] places = {
19         "/sbin/",
20         "/system/bin/",
21         "/system/sbin/",
22         "/data/local/sbin/",
23         "/data/local/bin/",
24         "/system/sd/sbin/",
25         "/system/bin/failsafe/",
26         "/data/local/"
27     };
28
29     for (final String where : places) {
30         if (new File(where + binaryName).exists()) {
31             result = true;
32             android.os.Process.killProcess(android.os.Process.myPid());
33         }
34     }
35
36     return result;
37 }
```

Code Snippet 4.2: Partial Listing

html

Sideload

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WAS IST DIE IDEE DAHINTER? WIE FUNKTIONIERT ES? WIE WIRD ES IMPLEMENTIERT? WIE SIEHT DAS RESULT AUS (EXAMPLE BILD)

<http://stackoverflow.com/questions/10809438/how-to-know-an-application-is-installed-from>
enforces installation from trusted sources to ensure original application developer should only distribute his software on in the app registered soruces, else app wont work an user is annoyed copied apps do not work now

Signature

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<http://developer.android.com/tools/publishing/app-signing.html>
<http://forum.xda-developers.com/showthread.php?t=2279813&page=5>

CONTRA

The unfortunate side effect of Lucky Patcher working with the Dalvik cache of an app is that the app developers cannot detect manipulations to their code through fingerprinting because the original code, located in “/data/app/<appName.apk>/classes.dex”, remains untouched. While it is allowed for an app to access its own optimized bytecode from the cache [32], computing a checksum or a hash for it doesn’t make sense because many optimizations to this bytecode are device-specific and cannot be known in advance. [47] !!!überprüfen!!!

Local Signature Check

This is my real text! Rest might be copied or not be checked!

local check whether signature is allowed
once in code
save to use signature in code?

—> was passiert wenn odex?

Flow Control

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zweimal LVL und eins failed immer, wenn stumpf modifiziert wird werden beide immer strue und somit erkennt man ob gepatcht wurde

visuelle elemente block für block freischalten, weg der definiert ist, wenn lvl licensed, wenn irgendwo geskippt wird fehlt ein element activate/kill in defined blocks, e.g. if vor switch, noch radikaler

4.1.3 Tampering Protection

man versucht sich vor neuen angriffen zu schützen indem man reengineering zeitintensiver macht

wenn anderes zb nicht geht weil algorithmus in der app, ohne redesign, wenn man auf kapiutel 1 sitzen bleibt, kein kontent server möglich, smartcard nicht einbauen will weil extra hardware/kosten,...

ref kapitel 1 macht gg lucky sicher, aber crakcbar wenn manuell, was kann man dagegen tun

now that the lvl is modified and the environment is enforced, the next goal is to prevent pirates from even starting to analyze the application, automatischer crack nicht mehr funktioniert, muster, andere mechanismen erkennt er nicht

does not help when standard version is implemented, that is why this is working best with customized implementation of LVL Reverse engineering and code protection are processes which are opposing each other, neither classified as good nor bad

"good" developer: malware detection and IP protection

"bad" developer: analysis for attack and analysis resistance

[41] it is not possible to 100 percent evade reengineering, but adding different methods to hide from plain sight of reengineering tools reengineering cannot be vermiede best is to apply techniqies to make it as hard a possible [47]

if they do not see what the app is doing, they cannot fix it

Application developers are interested in protecting their applications. Protection in this case means that it should be hard to understand what an application is doing and how its functionalities are implemented.

Reverse engineering of Android applications is much easier than on other architectures -see- high level but simple bytecode language

Obfuscation techniques protect intellectual property of software/license verification

possible code obfuscation methods on the Android platform focus on obfuscating Dalvik bytecode -see- limitations of current reverse engineering tools

This is my real text! Rest might be copied or not be checked! SOLUTION obfuscators are applied when compiling

(a) at source code and (b) bytecode level, Most existing open-source and commercial tools work on source code level

Java code is architecture-independent giving freedom to design generic code transformations. Lowering the obfuscation level to bytecode requires the algorithms applied to be tuned accordingly to the underlying architecture

[41]

a few dex obfuscators exist, with different approaches proguard or sdex, rename methods, field and calss names – break down string operations so as to chop hard coded strings or encrypt – can use dynamic class loading (dexloader classes to impede static analysis) can add dead code and dummy lopps (minor impact of performance) can also use goto into other onstructions

[44]

layout obfuscation most programmers name their variables, methods and calss in

meaningful way are preserved in generation of bytecode for dvm, hence still in dex, can be extracted by attacker, gain information and benefit when reengineering mangles names and identifiers that original meaning is lost while preserving correctness of syntax and semantics result is bytecode can be interpreted but dissable and decompile provide meaningless name for identifiers etc, e.g single letters or short combinations, welcome for strings section make it smaller only complicates but does not stop

[47]

will not protect against automated attack, does not alter flow of program makes more difficult for attackers to write initial attack removing symbols that would quickly reveal original structure number of commercial and open-source obfuscators available for Java that will work with Android [38]

Without proper naming of classes and methods it is much harder to reverse engineer an application, because in most cases the identifier enables an analyst to directly guess the purpose of the particular part. The program code itself will not be changed heavily, so the obfuscation by this tool is very limited.

hilft nicht direkt, aber um reengineering besser zu machen does not protect directly versus luckypatcher but in case of an custom implementation it makes the process of analyzing the app more time consuming

definition obfuscation, was macht es, wie funktioniert es, wer hat es erfunden, wie wendet man es an

"hard to reverse engineer" but without changing the behavior of this application, was heißt hard to reverse

parallele zu disassembler ziehen

Obfuscation cannot prevent reverse engineering but can make it harder and more time consuming. We will discuss which obfuscation and code protection methods are applicable under Android and show limitations of current reverse engineering tools

The following optimizers/obfuscators are common tools. (dadrin dann verbreitung preis etc erklären)

angriff beschreiben - library öffentlich - reengineering (ref meien tools)

davor schützen, jeden beliebigen test durch unäre antwort ersetzen, um das zu umgehen höher level als die license verification

=> tests die man auf unär modifizieren kann sind schwerer zu lokalisieren, hilft gg reengineering

in theory a good addition to the security of the application, but against luckypatcher directly since it works on java level in order to disguise the way the code works it

enforces increased initial effort an attacker has to spend in order to understand the code and thus reduces the likelihood of attackers to being motivated to crack the application in practice obfuscators are limited due to: reliance on android framework apis (remain unobfuscated) applications can be debugged jdwp and application debuggability at the java lvl can reveal information about the software popular enough obfuscators (dexguard) have deobfuscators professional tools cost a lot of money, you have to be commercial or have a real good idea in order to be worthwhile

Proguard

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A Java source code obfuscator. ProGuard performs variable identifiers name scrambling for packages, classes, methods and fields. It shrinks the code size by automatically removing unused classes, detects and highlights dead code, but leaves the developer to remove it manually [41]

open source tool shrinks, optimizes and obfuscates java .class files result - smaller apk files (use rprofits download and less space) - obfuscated code, especially layout obfuscation, harder to reverse engineer - small performance increase due to optimizations integrated into android build system, thus easy use default turned off minifyEnabled true proguardFiles getDefaultProguardFile('proguard-android.txt), 'proguard-rules.pro'

additional step in build process, right after java compiler compiled to class files, Proguard performs transformation on files removes unused classes, fields, methods and attributes which got past javac optimization step methods are inlined, unused parameters removed, classes and methods made private/static/final as possible obfuscation step name and identifiers mangled, data obfuscation is performed, packages flattened, methods renamed to same name and overloading differentiates them

after proguard is finished dx converts to classes.dex

[47]

identifier mangling, ProGuard uses a similar approach. It uses minimal lexical-sorted strings like a, b, c, ..., aa, ab, original identifiers give information about interesting parts of a program, Reverse engineering methods can use these information to reduce the amount of program code that has to be manually analyzed -see- neutralizing these information in order to prevent this reduction, remove any meta information about the behavior, meaningless string representation holdin respect to consistence means identifiers for the same object must be replaced by the same string, advantage of minimizing the memory usage, e development process in step "a" or step "b" string obfuscation, string must be available at runtime because a user cannot understand an obfuscated or encrypted message dialog, information is context, other is information itself, e.g. key, url, injective function and deobfuscation stub which con-

structs original at runtime so no behaviour is changed, does not make understanding harder since only stub is added but reduces usable meta information [54]

ProGuard is an open source tool which is also integrated in the Android SDK, free ProGuard is basically a Java obfuscator but can also be used for Android applications because they are usually written in Java // feature set includes identifier obfuscation for packages, classes, methods, and fields was kann er noch? -see- Besides these protection mechanisms it can also identify and highlight dead code and removed in a second, manual step Unused classes removed automatically by ProGuard. easy integration[3]

optimizes, shrinks, (barely) obfuscates, , reduces size, faster removes unnecessary/unused code merges identical code blocks performs optimizations removes debug information renames objects restructures code removes linenumbers, stacktrace annoying [33] [64]

Dexguard

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commercial Android obfuscator for bytecode and source code various techniques including strings encryption, encrypting app resources, tamper detection, removing logging code [41]

son of proguard, does everything that proguard does its a optimizer and shrinker, obfuscator/encrypter, does not stop reverse engineering automatic reflection, string encryption, asset/library encryption, class encryption(packing), application tamper protection, removes debug information may increase dex size, memory size; decrease speed [64]

obfuscation methods are a superset of ProGuards more powerful but also does not protect from disassembling the code

protects apps from reverse engineering and ahckign attacks makes apps smaller and faster specialized fr android protects code: obfuscation, hides sensitive strings,keys and entire algorithms [36]

Allatori

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commercial Android obfuscator name obfuscation, control flow flattening/obfuscation, debug info obfuscation, string encryption the result is a decreases dex size, memory, increases speed, removed debug code+ like Proguard+string encryption [64]

commercial product from Smardec addition to what Proguard does it offeres methods to provide program code, loops are modified so reengineering tools do not recognize it

as a loop adds complexity to algorithms and increases their size string obfuscation
[1] [2]

4.2 Replace Existing Mechanism

antwort des tests n icht mehr ok/no sondern verschlüsselter content

Now that the functionality of LuckyPatcher is analyzed, it is time to investigate in possible solutions for developers. Counter measurements preventing the cracking app from circumventing the license check mechanism are addressed in four different ways.

The first chapter covers functions to discover preconditions in the environment cracking apps use to discover weaknesses or need to be functional. The second chapter uses the acquired knowledge about LuckyPatcher to modify the code resulting in the patching being unsuccessful. In the third chapter presents methods to prevent the reengineering of the developers' application and thus the creation of custom cracks. Further hardware and external measurements are explained in the fourth chapter.

general suggestions by google <http://android-developers.blogspot.de/2010/09/securing-android-lvl-applications.html>

countermeasurements can be applied at different levels, when creating the software, when compiling the code to dex and on the dex file itself

goal is to

amazon/samsung not much to do since from company that is why the following not simple methods target lvl

patching application code is both most wide-spread and most powerful to interfere app logic ease is unfortunate for android developers, need better methods to protect vulnerable/precious code from attacks adding additional layer of security, making it a little harder for attackers

CHARAKTERIZED IN DIFFERENT TYPES, tampering protection to detect attack, modifications to enforce additional work in order to crack, methods directly targeting reengineering and additional external features, can be stacked [47]

4.2.1 Content Server

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By introducing service managed account, the user has to login on a server in order for the application to work an example is spotify, where the user logs in on a server and then can stream music without account it is not possible to obtain the stream details and even though when the stream details are obtained they can be encrypted with a user specific key the attacker does not have this way also an awesome algorithm can

be moved onto the server that the application is only a thin client, this way reverse engineering or pirating does not offer any value to the attacker

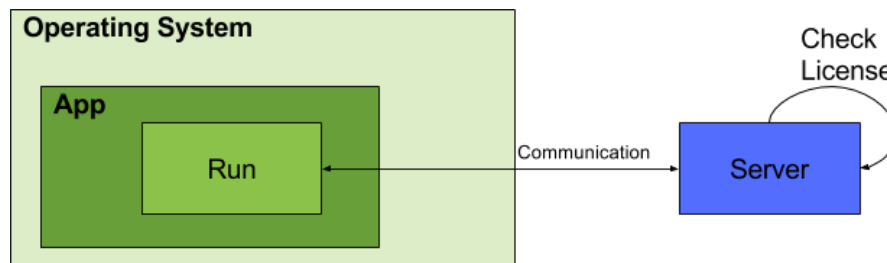


Figure 4.2: Abstraction of an application and a content server

since the logic is on a server, luckypthcer is not able to manipulate the logic, but it also has downsides first of all the business model must be enabled to be put onto a server in addition extra resources are needed, as knowledge and money to run a server, program it and maintain two apps means twice the work

4.2.2 Encryption

Encryption

Resource Decryption

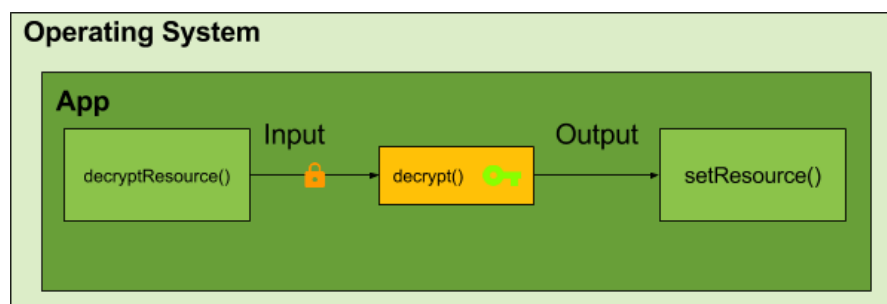


Figure 4.3: Encrypted resources which have to be decrypted on startup

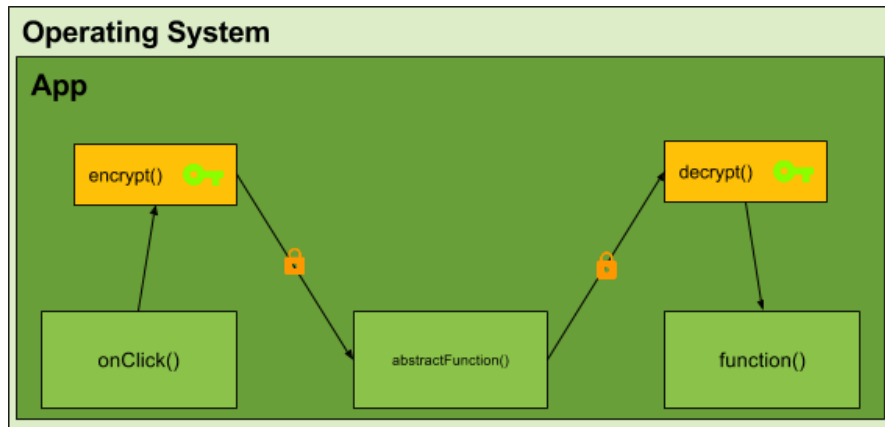


Figure 4.4: Encrypted actions to obfuscate dependencies

Action Obfuscator

Communication Decryption

Encryption

Secure Element

Secure Element

Secure Element

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can either be mounted in the sdcard slot or using an adapter for the usb interface accessed over reads and writes to the filesystem since it has to be small as a sd card and powered by the host system its hardware capabilities are restrained as well [56] with power as low as 25MHz complexe calculations would take too much time

simple tasks (beschreiben)

unbestechlich, jedoch boolean abfrage immer crackbar, deswegen andere sachen machen zB verschlüsseln

encrypted strings from the application can be decrypted by the secure element store property settings on it

encryption key can be stored on

no complexe tasks since low power

encryption inside app $x = \text{encrypt}(\text{"Hello"})$ $\text{function}(x)$

$\text{function}(\text{input}): y = \text{decrypt}(\text{input})$ <- auf handy case $y == \text{"Hello"}$

=> wenn falscher text dann random aktion/

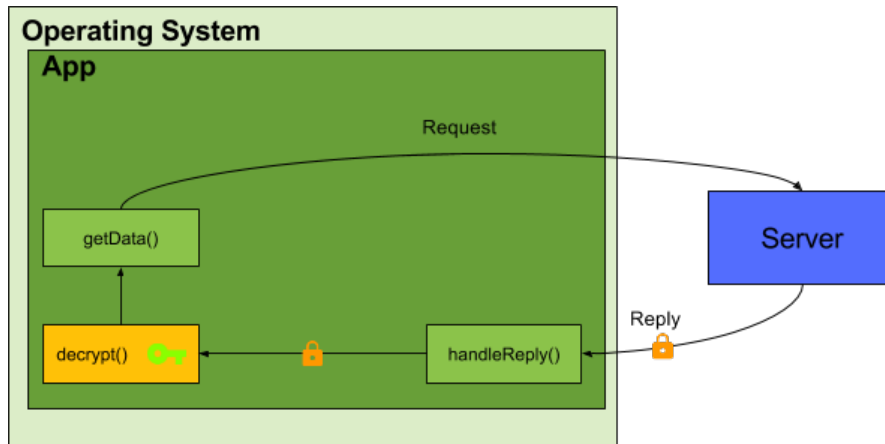


Figure 4.5: Encrypted communication with a server

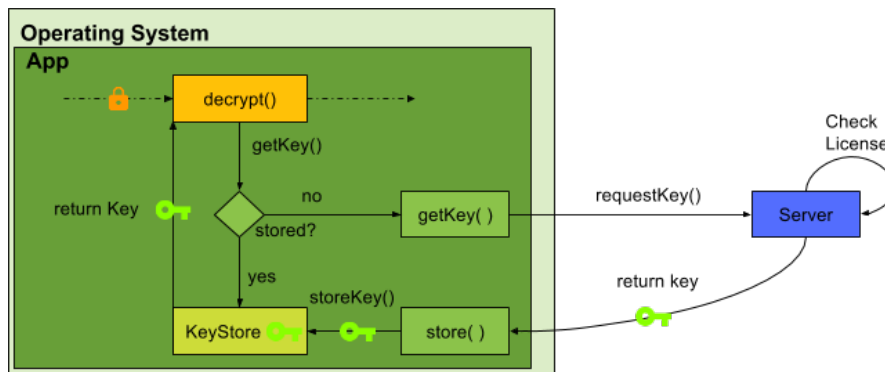


Figure 4.6: Retrieving the key after successful identification from the server and store it local on device

am besten wäre die smartcard wenn kommunikation über aussen geht, weil man da nichts faken kann bzw die app dann nicht funktionieren könnte, similar mit registriert auf dem server

<https://www.youtube.com/watch?v=rSH6dnUTDZo>

luckypatcher not able to attack since the logic is put onto a secure external device
nicht für boolean

same as internet service but extra hardare has to be bought people are lazy and do not want to have extra hardware when integrated into phone, it will take a long time until each phone supports it, e.g. was not able to use it on Nexus 6P and Nexus 7, Linux did not recognize it but mass storage was enabled, Nexus7 said OTG available but it did not work many different implementation fragmentate the market, there is not

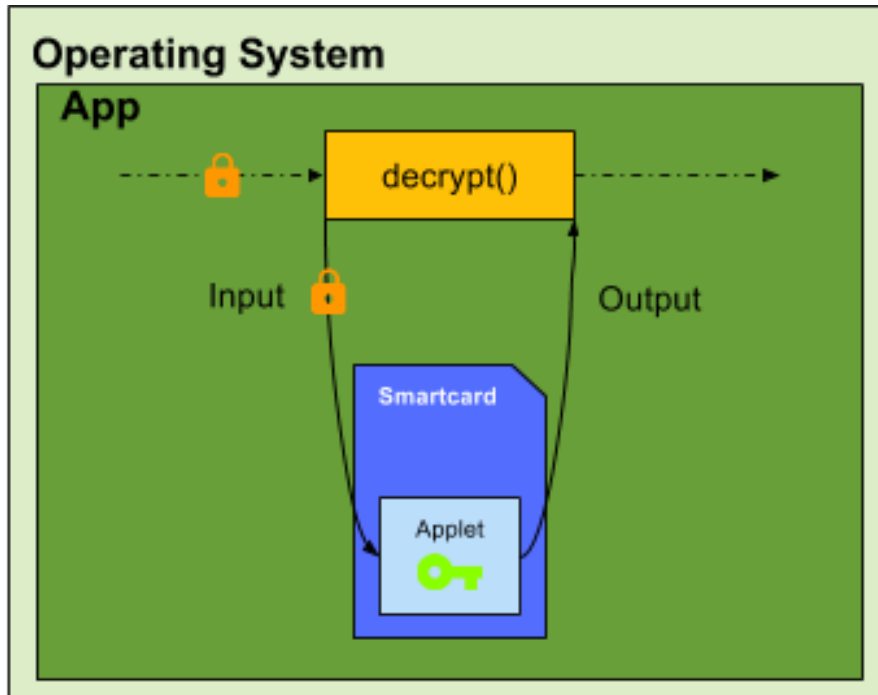


Figure 4.7: Decryption by using a smartcard

one single solution to focus on and push for market wide accepted solution
which are out there have major security flaws, smartcard itself can be attacked

encrypt inside app can be cracked when the source code is known $x = \text{encrypt}(\text{"Hello"})$
// $x = \text{"Hello"}$ function(x)

function(input): $y = \text{decrypt}(\text{input})$ // $y = \text{input}$ case $y == \text{"Hello"}$

DAP Verification normalerweise muss jede Applet, die auf so ein Secure Element/Smartcard etc. kommt mit ner Signatur unterschrieben sein ...

Waehrend ich Exploits finden konnte, die Dir erw. Zugriff geben, wenn du Applets installieren kannst, u.a.

4.3 Extensions to Environment

since dex code as we have seen is vulnerable to attacks and reengineering, the solution could be outside of the application, provided by either the environment or another hardware

level tiefer

4.3.1 Trusted Execution Environment

This is my real text! Rest might be copied or not be checked!

WAS IST ES? WAS MACHT ES? WIE IMPLEMENTIERT MAN?

promoted as be all end all solution for mobile security in theory isolated processing core with isolated memory, cannot be influenced by the outside and runs with privileged acces allows secure processing in the "secure world" that the "Normal world" cannot influence or beware of senisitive processing offloaded to protect information from malware

perfect wish: secure chip to process software that malware should not access, security related stuff like bankin, encryption

example Trustzone, Knox

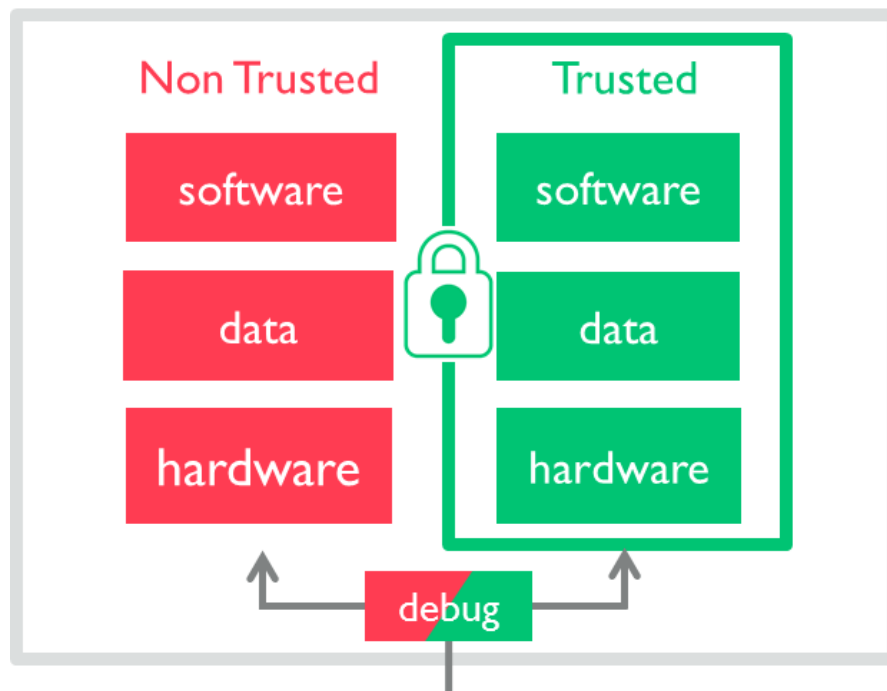


Figure 4.8: tee [20]

[25][20]

beispiele: new section trusted execution environment trusttronic letzte conference
samsung knox

luckypatcher not able to attack because it cannot access the TEE but before using it
as a safe solution soem problems have to be fixed

e.g. trustzone what is it already used for secure data storage, hardware configurations, bootloader/sim lock no hide from malware but user

architecture problems kernel to your kernel trustzone image stored unencrypted physical memory pointers

protection validation can be done by either using qualcomms or writing a custom one giant box, error by one has impact on all others

[25][20]

not accessible to anybody in general many different solutions, focus should be on one unique standard in order to fix the problems and make compatibility , google already started by integrating features of samsung's knox into android lollipop [52]

4.3.2 ART

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since dex is more like dangerous executable format and bears significant risks to app developers who do not use counter measurements against it

improve ART, already contains machine code which is hard to analyze and thus also difficult to find patches to apply with luckypatcher

already on the way, cannot be done from one day on the other, but right now not a protection against luckypatcher, will only be a solution when art code included in apks but why not now? Evaluation Why is Android not all ART now? Your applications still compile into Dalvik (DEX) code, Final compilation to ART occurs on the device, during install, Even ART binaries have Dalvik embedded in them, Some methods may be left as DEX, to be interpreted, Dalvik is much easier to debug than ART

[44]

zu ART. dex isnt dead yet, even with art still buried deep inside those oat files far easier to reverse engineer embedded dex than do so for oat

art is a far more advanced runtime architecture, brings android closer to ios native level performance vestiges of dex still remain to haunt performance, dex code is still 32bit very much still a shifting landscape, internal structures keep on changing, google isnt afraid to break compatibility, llvm integration likely to only increase and improve for most users the change is smooth, better performance and power consumption, negligible cost binary size increase, minor limitations on dex obfuscation remain, for optimal performance and obfuscation nothing beats JNI [44]

```

9  public static boolean checkInstall(final Context context) {
10     boolean result = false;
11     String[] luckypatcher = new String[]{
12         // Lucky patcher
13         "com.dimonvideo.luckypatcher",
14         // Another lucky patcher
15         "com.chelpus.lackypatch",
16         // Black Mart alpha
17         "com.blackmartalpha",
18         // Black Mart
19         "org.blackmart.market",
20         // Lucky patcher 5.6.8
21         "com.android.vending.billing.InAppBillingService.LUCK",
22         // Freedom
23         "cc.madkite.freedom",
24         // All-in-one Downloader
25         "com.allinone.free",
26         // Get Apk Market
27         "com.repodroid.app",
28         // CreeHack
29         "org.creeplays.hack",
30         // Game Hacker
31         "com.baseappfull.fwd"
32     };
33
34     for (String string : luckypatcher) {
35         if(checkInstallerName(context, string)){
36             result = true;
37         }
38
39         if (result) {
40             android.os.Process.killProcess(android.os.Process.myPid());
41         }
42     }
43
44     return result;
45 }
46
47 private static boolean checkInstallerName(Context context, String string) {
48     PackageInfo info;
49     boolean result = false;
50
51     try {
52         info = context.getPackageManager().getPackageInfo(string, 0);
53
54         if (info != null) {
55             android.os.Process.killProcess(android.os.Process.myPid());
56             result = true;
57         }
58
59     } catch (final PackageManager.NameNotFoundException ignored) {
60     }
61
62     if (result) {
63         android.os.Process.killProcess(android.os.Process.myPid());
64     }
65     return result;
66 }
67 }

```

```
15 public class Sideload {
16     private static final String PLAYSTORE_ID = "com.android.vending";
17     private static final String AMAZON_ID = "com.amazon.venezia";
18     private static final String SAMSUNG_ID = "com.sec.android.app.samsungapps";
19
20     public static boolean verifyInstaller(final Context context) {
21         boolean result = false;
22         final String installer = context.getPackageManager().getInstallerPackageName(context.
                getPackageName());
23
24         if (installer != null) {
25             if (installer.startsWith(PLAYSTORE_ID)) {
26                 result = true;
27             }
28             if (installer.startsWith(AMAZON_ID)) {
29                 result = true;
30             }
31             if (installer.startsWith(SAMSUNG_ID)) {
32                 result = true;
33             }
34         }
35         if (!result) {
36             android.os.Process.killProcess(android.os.Process.myPid());
37         }
38
39         return result;
40     }
```

Code Snippet 4.4: Partial Listing

```
51 public static boolean checkAppSignature(final Context context) {
52     //Signature used to sign the application
53     static final String mySignature = "...";
54     boolean result = false;
55
56     try {
57         final PackageInfo packageInfo = context.getPackageManager().getPackageInfo(context.
58             getPackageName(), PackageManager.GET_SIGNATURES);
59
60         for (final Signature signature : packageInfo.signatures) {
61             final String currentSignature = signature.toCharsString();
62             if (mySignature.equals(currentSignature)) {
63                 result = true;
64             }
65         }
66     } catch (final Exception e) {
67         android.os.Process.killProcess(android.os.Process.myPid());
68     }
69
70     if (!result) {
71         android.os.Process.killProcess(android.os.Process.myPid());
72     }
73
74     return result;
75 }
```

Code Snippet 4.5: Partial Listing

5 Conclusion

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research and also a valuable market for companies

Because source code can be easier recovered from an application in comparison to x86, there is a strong need for code protection and adoption of existing reverse engineering methods. Main parts of Android application functionalities are realized in Dalvik bytecode. So Dalvik bytecode is of main interest for this topic

Also, the Android system does not prevent modification of this bytecode during runtime, This ability of modifying the code can be used to construct powerful code protection schemata and so make it hard to analyze a given application.

[54]

current state of license verification on Android reverse engineering far too easy due to OS, extract/install allowed gaining root easy, allows everyone especially pirates avoiding protection mechanisms java was chosen to support a lot of hardware, java has bad protection

lvl popular but broken, has not done much since beginning of known issues [47]

auch wichtig weil wenn crackable dann upload zu stores und dann malware

<http://www.hotforsecurity.com/blog/mobile-app-development-company-fights-off-android-malware-with-obfuscation-tool-3717.html>

5.1 Summary

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jedes chapter beschreiben

5.2 Discussion

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clear in beginnign that lvl not sufficiently safe with current technology unclear degree and fixavle

shortly after start insufficient resilience against reverse engineering, not exclusively to lvl thus shift from lvl protection to general protection against reverse engineering, decompilation and patching

eternal arms race no winning solution against all cases, just small pieces quantitative improvement no qualitatively improve resilience limited to quantitative resilience, matter of time until small steps generate more work for reengineering, ggf lower motivation for cracker only matter of time until patching tools catch up, completely new protection schemes need to be devised to counter those [47]

not a question of if but of when bytecode tool to generate the license library on the fly, using random permutations and injecting it everywhere into the bytecode with an open platform we have to accept a crack will happen [40]

um das ganze zu umgehen content driven, ala spotify, jedoch ist dies nicht mit jeder geschäftsidee machbar

alles hilft gegen lucky patcher auf den ersten blick, jedoch custom patches, welche LuckyPatcher anbietet[47], können es einfach umgehen, deswegen hilft nur reengineering schwerer zu machen viele piraten sind nicht mehr motiviert wenn es zu schwer ist every new layer of obfuscation/modification adds another level complexity

solange keine bessere lösung vorhanden unique machen um custom analysis und reengineering zu enforzen und dann viele kleine teile um die schwierigkeit des reengineerens und angriffs zu erschweren und viel zeit in anspruch zu nehmen um die motivation der angreifer zu verringern und somit die app zu schützen

5.3 Future Work

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lvl has room for improvement art promising but not root issue, dex is distributed and art compilation to native on device needs to become relevant so developers can release art only apps, native code and no issue with reverse engineering stop/less important until lvl see major update custom improvements have to be done [47]

nicht mehr zu rettendes model, dex hat zu viele probleme, google bzw die anderen anbieter müssen eine über lösung liefern denn für den einzelnen entwickler so etwas zu erstellen ist nicht feasible, da einen mechanismus zu erstellen komplexer ist als die app itself

se/tee muss es eine lösung geben sonst braucht man für verschiedene apps verschiedene se, gemeinsame kraft um die eine lösung zu verbessern und nicht lauter schweizer käse zu ahben

google hat schon sowas wie google vault

all papers with malware and copyright protection is interesting since they also want to hide their code

List of Figures

2.1	Android's architecture [48]	9
2.2	APK build process [44]	10
2.3	.dex file format [44]	12
2.4	.jar to APK transformation [22]	12
2.5	Installing an APK on a device [17]	14
2.6	oat	16
2.7	art	17
2.8	art2	18
2.9	artarch	19
2.10	oatdex	19
2.11	Google's implementation of license checking [12]	21
2.12	Developer preferences in the Amazon developer console [4]	24
2.13	Amazon library structure in decompiled application	24
2.14	Abstraction of the current license verification mechanism. The library is represented by (1)	27
2.15	Java .class and .dex can be transformed bidirectional [44]	28
2.16	Overview of build and reverse engineering of an APK [44]	29
3.1	c	39
3.2	Abstraction of the current attack on the license verification mechanism	50
4.1	Introduction of additional tests to check environment and integrity of the application	54
4.2	Abstraction of an application and a content server	64
4.3	Encrypted resources which have to be decrypted on startup	64
4.4	Encrypted actions to obfuscate dependencies	65
4.5	Encrypted communication with a server	66
4.6	Retrieving the key after successful identification from the server and store it local on device	66
4.7	Decryption by using a smartcard	67
4.8	tee [20]	68

List of Tables

3.1	Functionality for the test apps before and after patching	42
3.2	Overview of License Verification Library patching patterns applied by each modus	49

List of Code Snippets

2.1	Include permission to check the license in AndroidManifest.xml [9] . .	22
2.2	Setting up the LVL license check call	22
2.3	LVL license check callback	23
2.4	Amazon's onCreate() injection to call Kiwi license verification as well .	25
2.5	Setting up the Zirconia license check call	26
2.6	Zirconia license check callback	26
2.7	Script to extract the .dex byte code from the APK	31
2.8	dex hexdump example	31
2.9	Script to generate the corresponding smali code for a given APK	33
2.10	smali example	33
2.11	Script to decompile to Java using androguard	35
2.12	Java code example using androguard	35
2.13	Script to decompile to Java using JADX	36
2.14	Java code example using JADX	36
2.15	Script to compare the original and manipulated APK to see the modifi- cations in the different presentations	37
3.1	Diff on Dex level for N1 pattern	42
3.2	Diff on Smali level for N1 pattern	42
3.3	Diff on Java level for N1 pattern (abstracted)	43
3.4	Diff on Dex level for N2 pattern	43
3.5	Diff on Smali level for n2 pattern	43
3.6	Diff on Java level for N2 pattern (abstracted)	43
3.7	Diff on Dex level for N3 pattern	44
3.8	Diff on Smali level for N3 pattern	44
3.9	Diff on Java level for N3 pattern (abstracted)	44
3.10	Diff on Dex level for N4 patch	45
3.11	Diff on Smali level for N4 patch	45
3.12	Diff on Java level for N4 patch (abstracted)	45
3.13	Diff on Dex level for N6 patch	46
3.14	Diff on Smali level for N6 patch	46
3.15	Diff on Java level for N6 patch (abstracted)	46

3.16	Diff on Java level for N7 patch (abstracted)	47
3.17	Diff on Dex level for Amazon patch	47
3.18	Diff on Smali level for Amazon patch	47
3.19	Diff on Java level for Amazon patch (abstracted)	47
3.20	Diff on Dex level for Samsung patch	48
3.21	Diff on Smali level for Samsung patch	48
3.22	Diff on Java level for Samsung patch (abstracted)	49
4.1	asd[26]	56
4.2	Partial Listing	57
4.3	Partial Listing	70
4.4	Partial Listing	71
4.5	Partial Listing	72

Bibliography

- [1] allatori. *Allatori Java Obfuscator*. URL: <http://www.allatori.com/> (visited on 01/22/2016).
- [2] allatori. *Documentation*. URL: <http://www.allatori.com/doc.html> (visited on 01/22/2016).
- [3] allatori. *ProGuard*. URL: <http://developer.android.com/tools/help/proguard.html> (visited on 01/22/2016).
- [4] Amazon. *Amazon Developer Service*. URL: <https://developer.amazon.com/> (visited on 02/02/2016).
- [5] Amazon. *Amazon Send Developers a Welcome Package*. URL: <http://www.androidheadlines.com/2010/10/amazon-send-developers-a-welcome-package.html> (visited on 01/19/2016).
- [6] Amazon. *Introducing Amazon Appstore for Android*. URL: <http://phx.corporate-ir.net/phoenix.zhtml?c=176060&p=irol-newsArticle&ID=1541548> (visited on 01/19/2016).
- [7] Android. *ART and Dalvik*. URL: <https://source.android.com/devices/tech/dalvik/index.html> (visited on 02/15/2016).
- [8] Android. *Configuring ART*. URL: <https://source.android.com/devices/tech/dalvik/configure.html> (visited on 02/15/2016).
- [9] Android Developers. *Adding Licensing to Your App*. URL: <https://developer.android.com/google/play/licensing/adding-licensing.html> (visited on 01/18/2016).
- [10] Android Developers. *Application Fundamentals*. URL: <http://developer.android.com/guide/components/fundamentals.html> (visited on 01/18/2016).
- [11] Android Developers. *Dalvik Executable format*. URL: <https://source.android.com/devices/tech/dalvik/dex-format.html> (visited on 02/02/2016).
- [12] Android Developers. *Licensing Overview*. URL: <https://developer.android.com/google/play/licensing/overview.html> (visited on 01/18/2016).
- [13] Android Developers. *Licensing Reference*. URL: <https://developer.android.com/google/play/licensing/licensing-reference.html> (visited on 01/21/2016).

- [14] Android Developers. *Setting Up for Licensing*. URL: <https://developer.android.com/google/play/licensing/setting-up.html> (visited on 01/18/2016).
- [15] Android Developers. *Settings.Secure*. URL: <http://developer.android.com/reference/android/provider/Settings.Secure.html> (visited on 02/16/2016).
- [16] Android Developers Blog. *Announcing the Android 1.0 SDK, release 1*. URL: <http://android-developers.blogspot.de/2008/09/announcing-android-10-sdk-release-1.html> (visited on 02/15/2016).
- [17] I. R. Anwar Ghuloum Brian Carlstrom. *The ART runtime*. URL: <https://www.youtube.com/watch?v=EB1TzQsUo0w> (visited on 02/02/2016).
- [18] APKSFREE.com. *diff*. URL: <http://www.androidapksfree.com/app/blackmart-alpha-latest-version/>.
- [19] Apple. *Piracy Prevention*. URL: <http://www.apple.com/legal/intellectual-property/piracy.html> (visited on 01/18/2016).
- [20] ARM. *TrustZone*. URL: <http://www.arm.com/products/processors/technologies/trustzone/index.php> (visited on 01/24/2016).
- [21] Blackmart. *Blackmart Alpha*. URL: <http://www.blackmart.us/> (visited on 01/20/2016).
- [22] D. Bornstein. *Dalvik VM Internals*. URL: <https://sites.google.com/site/io/dalvik-vm-internals> (visited on 02/02/2016).
- [23] L. Botezatu. *Manipulation und Diebstahl im Google Play Store*. URL: <http://www.bitdefender.de/hotforsecurity/manipulation-und-diebstahl-im-google-play-store-2673.html> (visited on 01/16/2016).
- [24] J. Callaham. *Smartphone OS Market Share*. URL: <http://www.androidcentral.com/google-says-there-are-now-14-billion-active-android-devices-worldwide> (visited on 01/16/2016).
- [25] J. T. Charles Holmes. *An Infestation of Dragons - Exploring Vulnerabilities in the ARM TrustZone Architecture*. URL: https://usmile.at/sites/default/files/androidsecuritysymposium/presentations/Thomas_Holmes_AnInfestationOfDragons.pdf (visited on 01/24/2016).
- [26] ChelpuS. *Lucky Patcher*. URL: <http://lucky-patcher.netbew.com/> (visited on 01/09/2016).
- [27] E. Chu. *Licensing Service For Android Applications*. URL: <http://android-developers.blogspot.de/2010/07/licensing-service-for-android.html> (visited on 01/18/2016).

- [28] comScore. *comScore Reports November 2015 U.S. Smartphone Subscriber Market Share*. URL: <https://www.comscore.com/ger/Insights/Market-Rankings/comScore-Reports-November-2015-US-Smartphone-Subscriber-Market-Share> (visited on 01/19/2016).
- [29] CrackAPK. *Android APK Cracked*. URL: <http://www.crackapk.com/> (visited on 01/20/2016).
- [30] Dex Protector. *Dex Protector*. URL: <https://dexprotector.com/> (visited on 02/15/2016).
- [31] M. Dziatkiewicz. *Preventing Android applications piracy possible, requires diligence, planning*. URL: <http://www.fiercedeveloper.com/story/preventing-android-applications-piracy-possible-requires-diligence-planning/2012-08-14> (visited on 01/26/2016).
- [32] D. Ehringer. *The Dalvik Virtual Machine Architecture*. Mar. 2010.
- [33] D. Galpin. *Proguard, Android, and the Licensing Server*. URL: <http://android-developers.blogspot.de/2010/09/proguard-android-and-licensing-server.html> (visited on 01/22/2016).
- [34] Google Developers. *AdMob for Android*. URL: <https://developers.google.com/admob/android/quick-start> (visited on 01/26/2016).
- [35] Google Play. *Google Play*. URL: <https://play.google.com/store?hl=de> (visited on 01/26/2016).
- [36] GuardSquare. *DexGuard - The strongest Android obfuscator, protector, and optimizer*. URL: <https://www.guardsquare.com/dexguard> (visited on 01/22/2016).
- [37] IDC Research, Inc. *Smartphone OS Market Share*. URL: <http://www.idc.com/prodserv/smartphone-os-market-share.jsp> (visited on 01/16/2016).
- [38] T. Johns. *Securing Android LVL Applications*. URL: <http://android-developers.blogspot.de/2010/09/securing-android-lvl-applications.html> (visited on 01/18/2016).
- [39] E. Johnston. *Mobile Game Piracy Isn't All Bad, Says Monument Valley Producer (Q&A)*. URL: <http://recode.net/2015/01/06/mobile-game-piracy-isnt-all-bad-says-monument-valley-producer-qa/> (visited on 01/18/2016).
- [40] Kevin. *How the Android License Verification Library is Lulling You into a False Sense of Security*. URL: <http://www.digipom.com/how-the-android-license-verification-library-is-lulling-you-into-a-false-sense-of-security/> (visited on 01/18/2016).

- [41] A. Kovacheva. "Efficient Code Obfuscation for Android." Master's Thesis. Université de Luxembourg, Faculty of Science, Technology and Communication, Aug. 2013.
- [42] M. Kroker. *App-Markt in Deutschland 2014: Umsätze im Google Play Store erstmals größer als bei Apple*. URL: <http://blog.wiwo.de/look-at-it/2015/02/25/app-markt-in-deutschland-2014-umsatze-im-google-play-store-erstmals-groesser-als-bei-apple/> (visited on 01/16/2016).
- [43] J. Levin. *Android Security - New threats, New Capabilities*. URL: <http://newandroidbook.com/files/Andevcon-Sec.pdf> and (visited on 01/18/2016).
- [44] J. Levin. *Dalvik and ART*. Dec. 2015.
- [45] M. Liersch. *Android Piracy*. URL: <https://www.youtube.com/watch?v=TNnccRimhsI> (visited on 01/22/2016).
- [46] S. Morrow. *Rooting Explained + Top 5 Benefits Of Rooting Your Android Phone*. URL: <http://www.androidpolice.com/2010/04/15/rooting-explained-top-5-benefits-of-rooting-your-android-phone/> (visited on 01/18/2016).
- [47] M.-N. Muntean. "Improving License Verification in Android." Master's Thesis. Technische Universität München, Fakultät für Informatik, May 2014.
- [48] Obscure - community site theme. *Understanding the Android software stack*. URL: <http://maat-portfolio.mut.ac.th/~r4140027/?p=116> (visited on 01/27/2016).
- [49] Oracle. *JAR File Specification*. URL: <http://docs.oracle.com/javase/6/docs/technotes/guides/jar/jar.html> (visited on 02/15/2016).
- [50] R. Price. *DexFile*. URL: <http://www.businessinsider.com/android-app-profitability-v-ios-2015-1?IR=T> (visited on 01/16/2016).
- [51] Runtastic. *Runtastic PRO Laufen & Fitness*. URL: <https://play.google.com/store/apps/details?id=com.runtastic.android.pro2&hl=de> (visited on 01/20/2016).
- [52] Samsung. *A closer look at KNOX contributing in Android*. URL: <https://www.samsungknox.com/en/androidworkwithknox> (visited on 01/24/2016).
- [53] Samsung. *How to protect your app from illegal copy using Samsung Application License Management (Zirconia)*. URL: <http://developer.samsung.com/technical-doc/view.do?v=T0000000062L> (visited on 01/19/2016).
- [54] P. Schulz. "Code Protection in Android." Lab Course. Friedrich-Wilhelms-Universität Bonn, Institute of Computer Science, July 2012.

- [55] M. T. Serrafiero. *Piracy Testimonies, Causes and Prevention*. URL: <http://www.xda-developers.com/piracy-testimonies-causes-and-prevention/> (visited on 01/16/2016).
- [56] ST life.augmented. *Allatori Java Obfuscator*. URL: <http://www.st.com/web/catalog/mmc/FM143/SC1282/PF259413> (visited on 01/24/2016).
- [57] stack overflow. *Posts containing 'Android, Piracy'*. URL: <http://stackoverflow.com/search?q=android+piracy> (visited on 01/26/2016).
- [58] stack overflow. *Posts containing 'Lucky Patcher'*. URL: <http://stackoverflow.com/search?q=lucky+patcher> (visited on 01/26/2016).
- [59] statista. *Number of apps available in leading app stores as of July 2015*. URL: <https://its.uncg.edu/Software/Licensing/> (visited on 01/16/2016).
- [60] P. Steinlechner. *Cracker beißen sich die Zähne an "Just Cause 3" aus*. URL: <http://www.sueddeutsche.de/digital/illegale-kopien-von-computerspielen-cracker-beissen-sich-die-zaehne-an-just-cause-aus-1.2810482> (visited on 01/26/2016).
- [61] Stericson. *Busybox - Android-Apps auf Google Play*. URL: <http://www.androidheadlines.com/2010/10/amazon-send-developers-a-welcome-package.html> (visited on 01/19/2016).
- [62] TeamSpeak Systems GmbH. *TeamSpeak 3*. URL: <https://play.google.com/store/apps/details?id=com.teamspeak.ts3client&hl=de> (visited on 01/20/2016).
- [63] The University of North Carolina Greensboro. *Software Licensing*. URL: <http://www.statista.com/statistics/276623/number-of-apps-available-in-leading-app-stores/> (visited on 01/16/2016).
- [64] J. S. Tim Strazzare. *Android Hacker Protection Level 0*. URL: <https://www.youtube.com/watch?v=6vFcEJ2jg0w> (visited on 01/22/2016).
- [65] ubuntuusers. *diff*. URL: <https://wiki.ubuntuusers.de/diff> (visited on 02/02/2016).
- [66] J. Underwood. *Today Calendar's Piracy Rate*. URL: <https://plus.google.com/+JackUnderwood/posts/jWs84EPNyNS> (visited on 01/16/2016).
- [67] WugFresh. *Nexus Root Toolkit v2.1.4*. URL: <http://www.wugfresh.com/nrt/> (visited on 02/16/2016).