From Large Scale Analysis to Dynamic Deobfuscation

The Woes of Android Reverse Engineering

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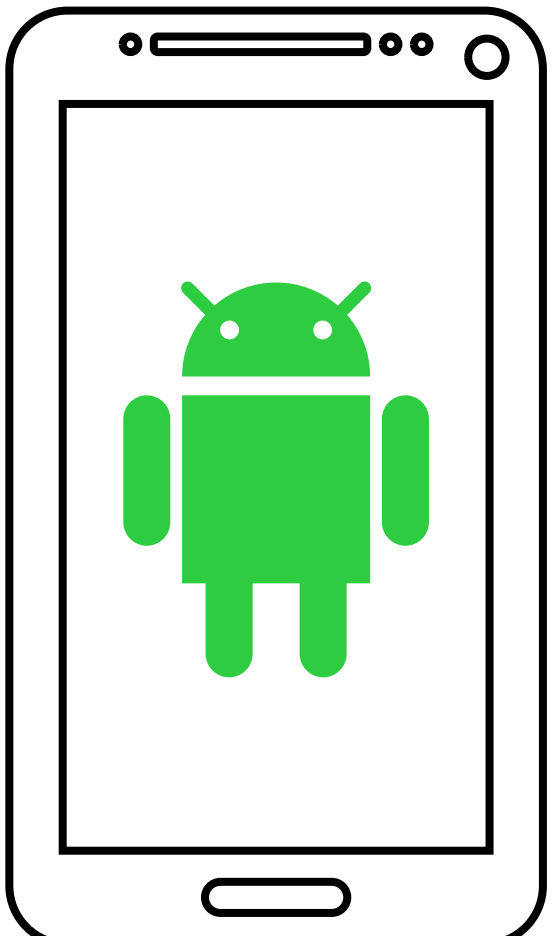
2025-12-09

Google

Smartphones are computers

Android = Linux + Android Runtime (ART)

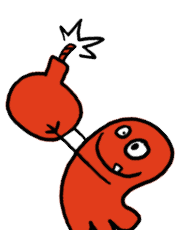
APK = computer program (Java-ish)

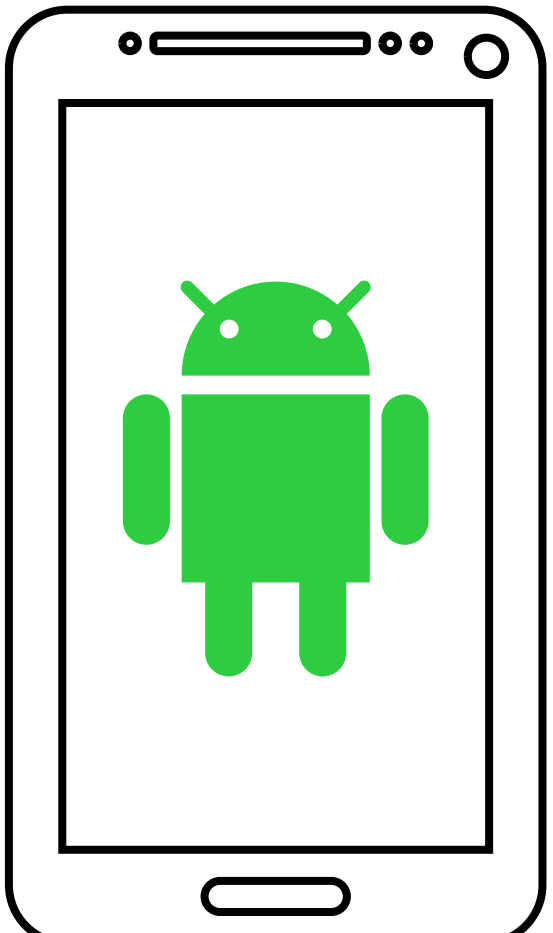


Personal Data and PII

$\Rightarrow$

Ransomware/Spyware





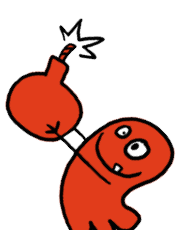
Personal Data and PII

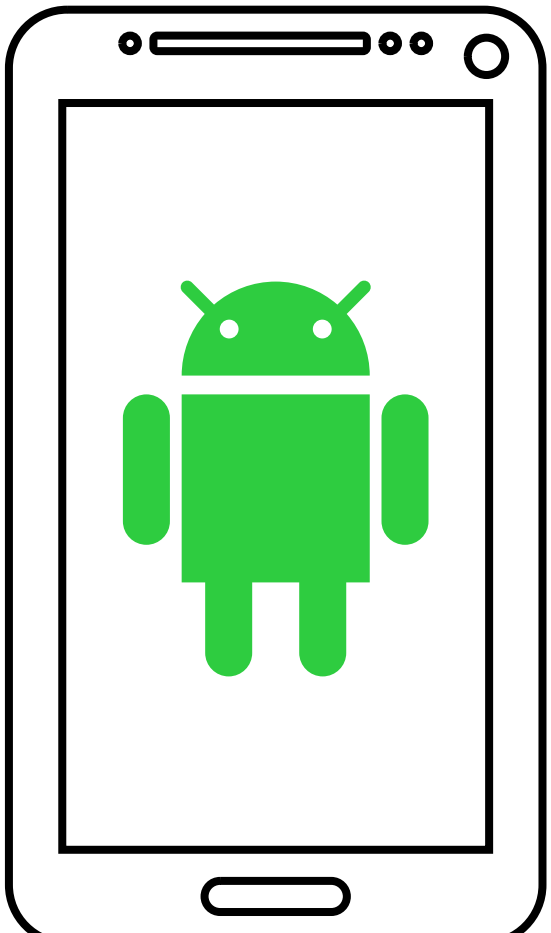
Computing Power

$\Rightarrow$

Ransomware/Spyware

Cryptojacker





Personal Data and PII

Computing Power

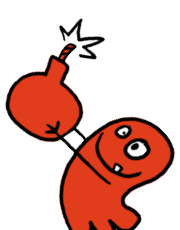
Phone

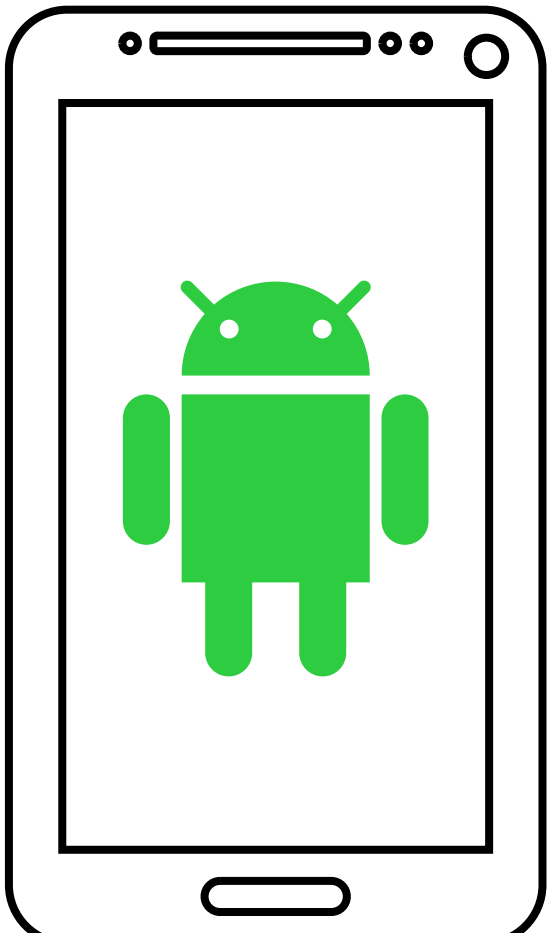
$\Rightarrow$

Ransomware/Spyware

Cryptojacker

Expander (phone billing)





Personal Data and PII

Computing Power

Phone

Mic, Camera, Geolocalisation

$\Rightarrow$

Ransomware/Spyware

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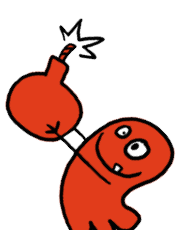
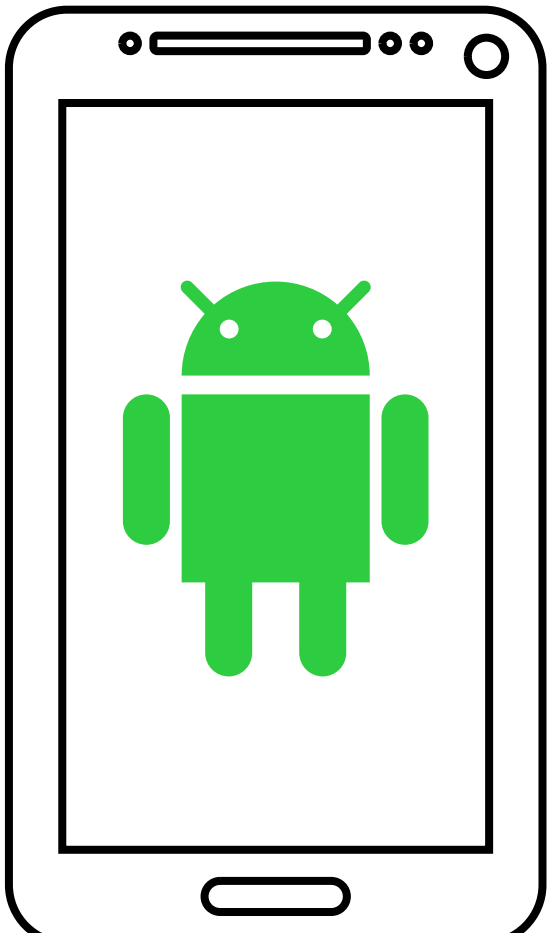
Expander (phone billing)

Stalkerware





Obfuscation

Applications might use **obfuscation** to either:

- protect their Intellectual Property
- hide malicious behaviour

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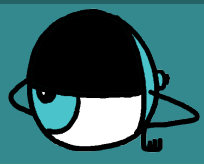
We will focus on two techniques:

- **Dynamic Code Loading**
- **Reflection**

Obfuscation — Example



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2  String className = "W5f3 [...] 3sls=";
3  String methodName = "n6WGYJzjDrUvR9cYljlNlw==";
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5  ClassLoader cl = new InMemoryDexClassLoader(
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8  );
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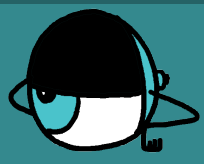
Obfuscation — Dynamic Code Loading



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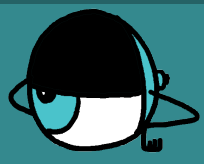
Obfuscation — Reflection



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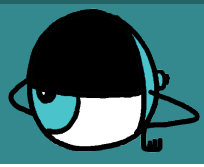

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Obfuscation — Deobfuscated

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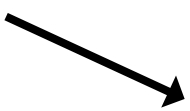
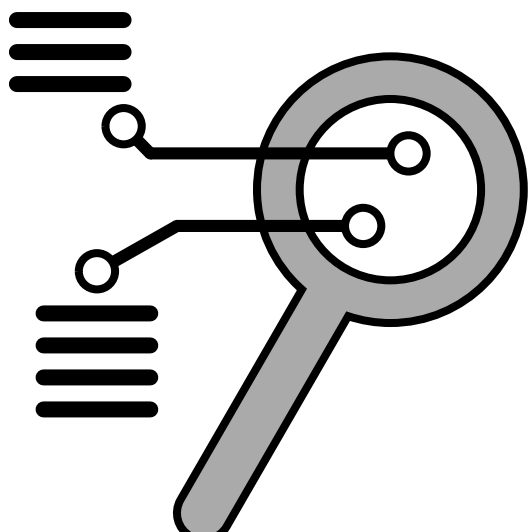
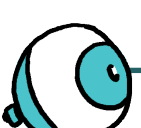


```
1  public class Foo {
2    public static String
     bar(String arg) {
…                    …
13   }
14 }
```

```
1  String ret =
   Foo.bar("FooBar");
```

Analysis Methods

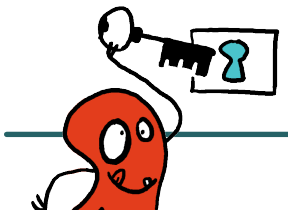




Dynamic Analysis

Run the application

Static Analysis

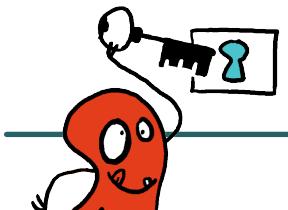


Dynamic Analysis

Run the application

See dynamically loaded bytecode

Static Analysis



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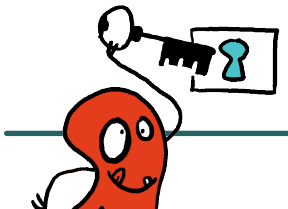
See reflection calls

Static Analysis



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See reflection calls

Limited by code coverage

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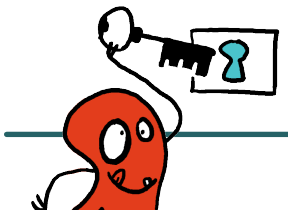

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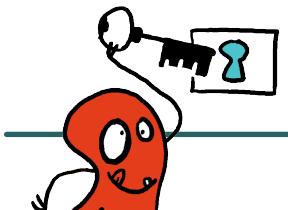


Dynamic Analysis

Run the application

See dynamically loaded bytecode

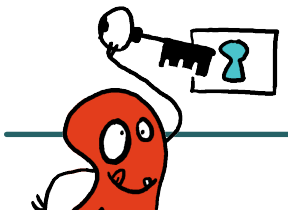
See reflection calls

Limited by code coverage

Static Analysis

Do **not** run the application

Not limited by code coverage



Dynamic Analysis

Run the application

See dynamically loaded bytecode

See reflection calls

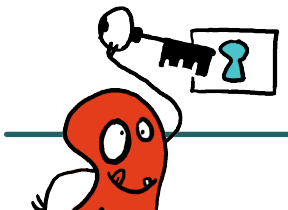
Limited by code coverage

Static Analysis

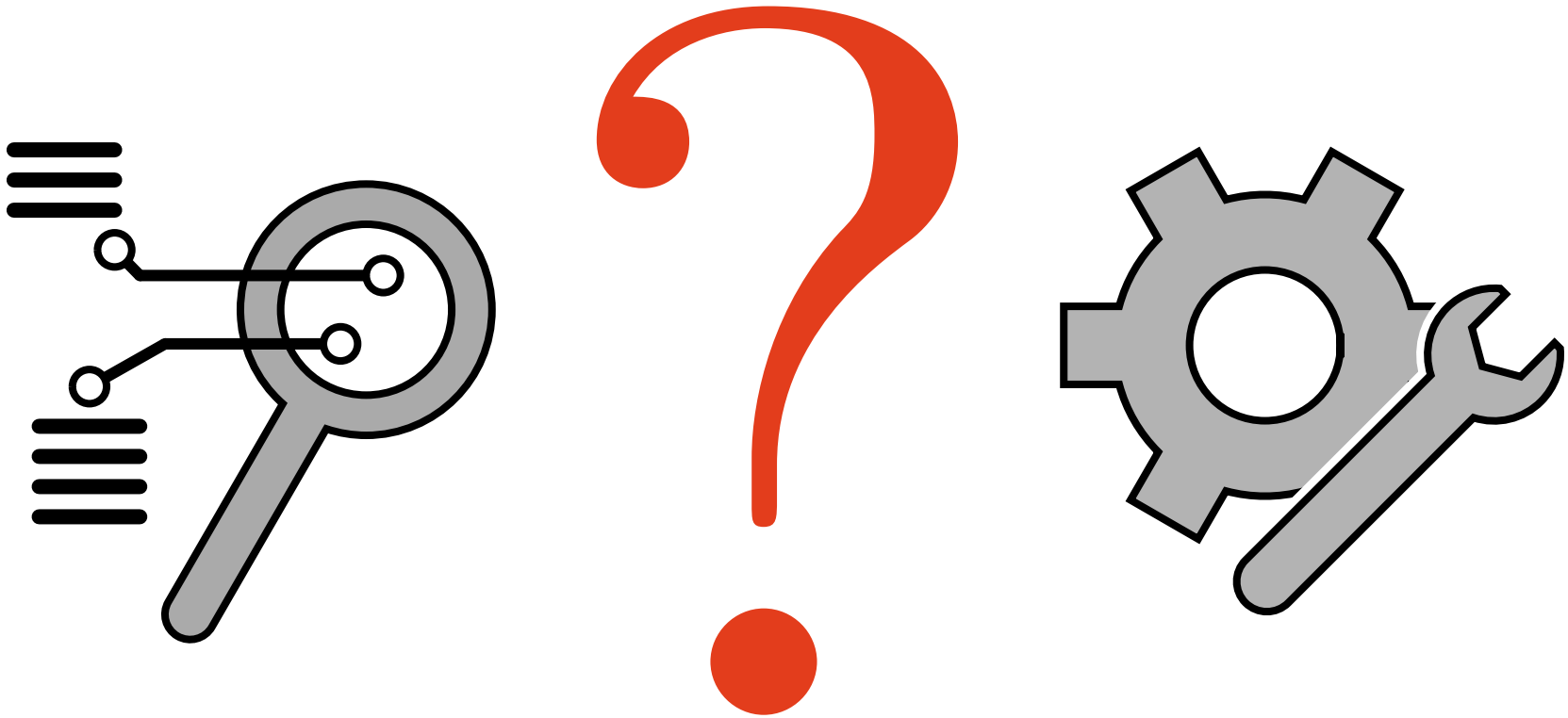
Do **not** run the application

Not limited by code coverage

But only for the **code available**



Which Tools are *really* Working?



Problem Statement 1

Which static analysis tool to use?

To what extent are previously published Android analysis tools still usable today, and what factors impact their reusability?

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```
1 class A {
2   public static void foo() {
3     B b = new B();
4     b.bar();
5   }
6 }
```

Where is the class loader?

Problem Statement 2

Used to select classes implementation

What is the default Android class loading algorithm, and does it impact static analysis?

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More complex than it looks

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Doubious documentation

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Problem Statement 2

Used to select classes implementation

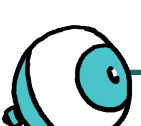
More complex than it looks

Doubious documentation

Not studied in the context of Android Static Analysis

What is the default Android class loading algorithm, and does it impact static analysis?

Can we Deobfuscate?



Deobuscation

Dynamic Analysis

Easier to solve Dynamic Code Loading and Reflection Calls

Static Analysis

Better code coverage

Deobuscation

Dynamic Analysis

Easier to solve Dynamic Code Loading and Reflection Calls

Static Analysis

Better code coverage

Can we combine both?

Problem Statement 3

Dynamic analysis is good against DCL and reflection

Can we use instrumentation to provide dynamic code loading and reflection data collected dynamically to static analysis tools and improve their results?

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Problem Statement 3

Dynamic analysis is good against DCL and reflection

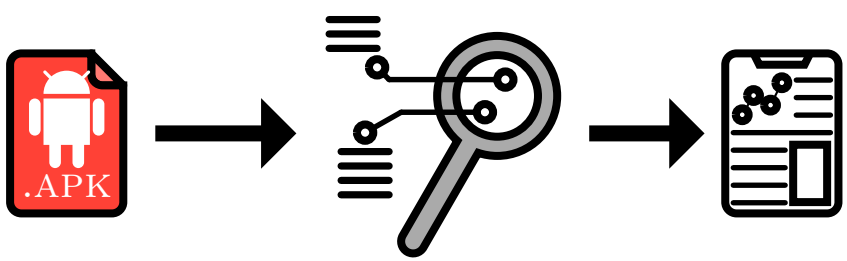
Dynamic analysis is limited by code coverage

Static analysis is not

How to use existing tools without modifying them?

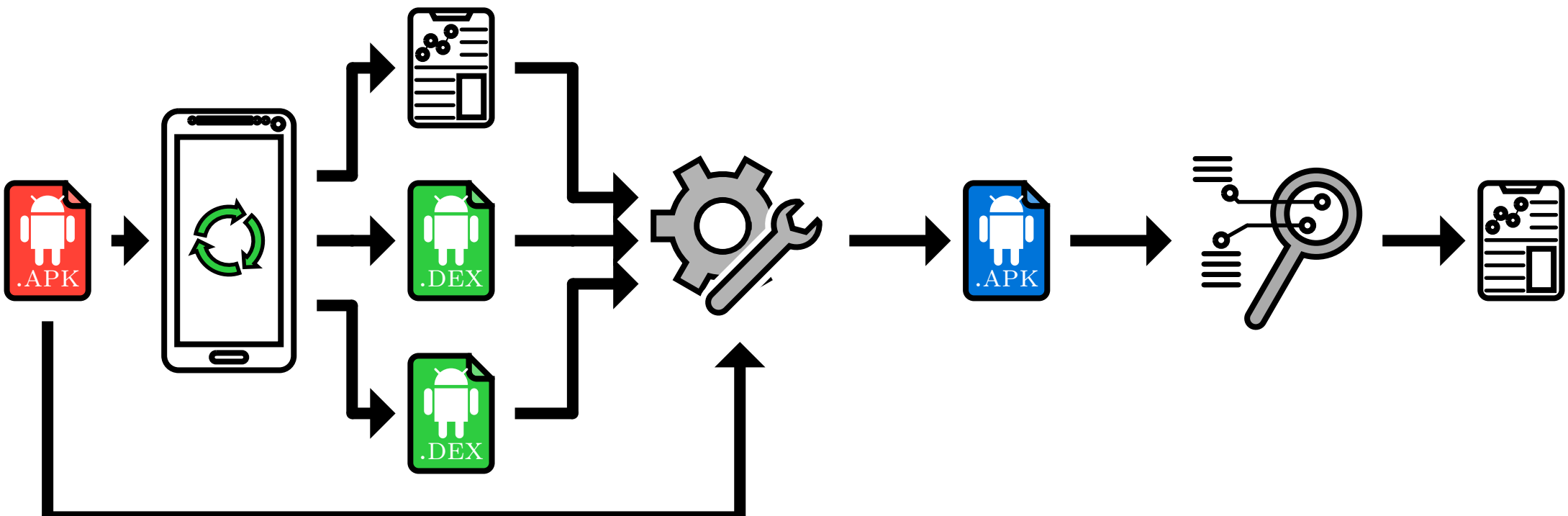
Can we use instrumentation to provide dynamic code loading and reflection data collected dynamically to static analysis tools and improve their results?

PB 1: Static Analysis
are the tools working?



PB 2: Do Static Tools match Android Runtime?

PB 3: Improve any Static Tools with dynamic analysis?



Tool Reusability

State of the Art

Li *et al.* (2017):

Systematic literature review for Android static analysis (38 tools)

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Lists 31 open-sourced tools

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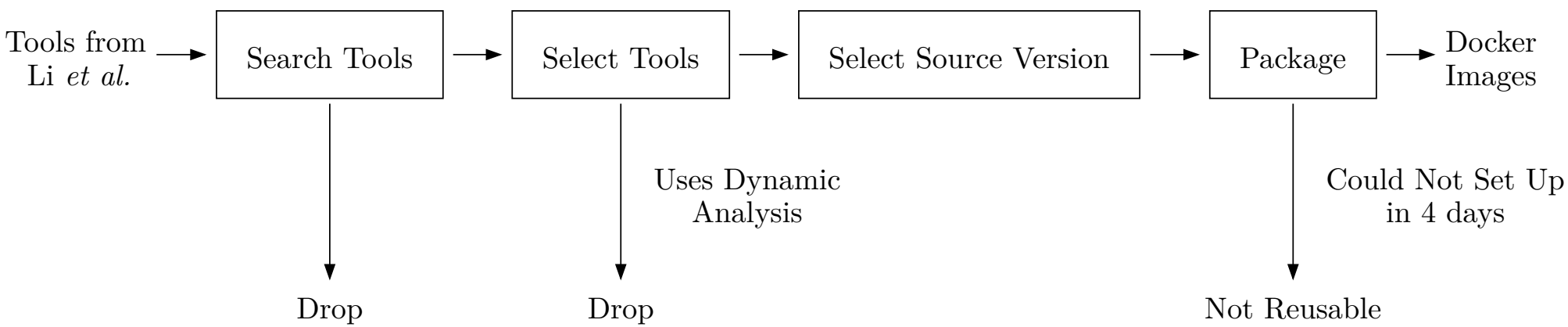
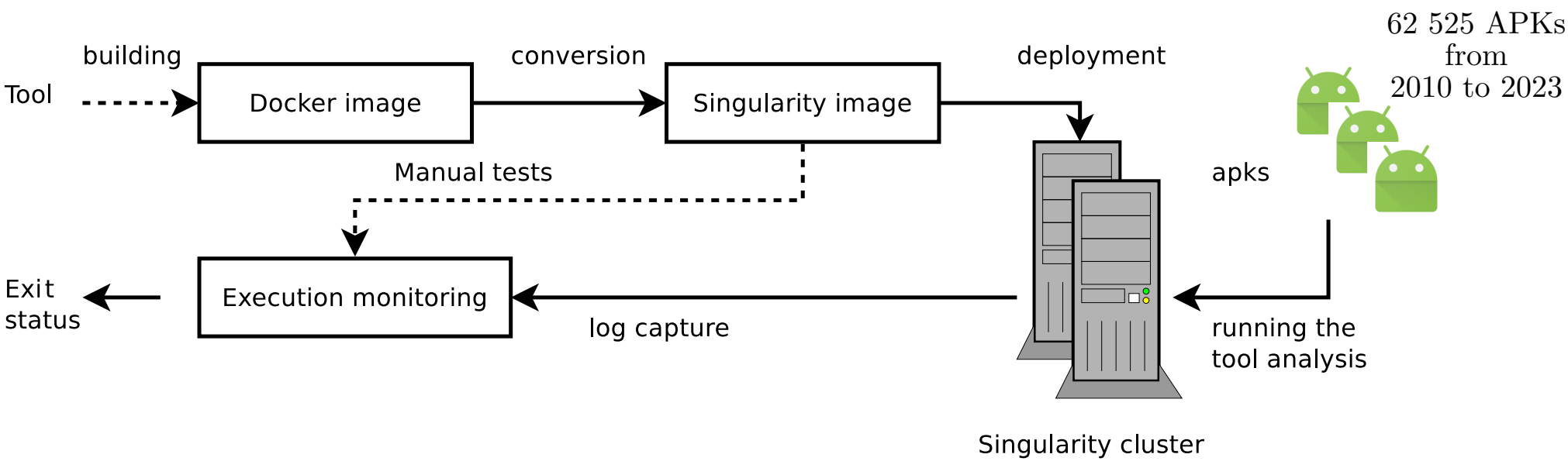
- Tests analysing 16 real-world applications
- Raises concerns about reusability and analysis of real-world applications

Methodology: Packaging Static Analysis Tools



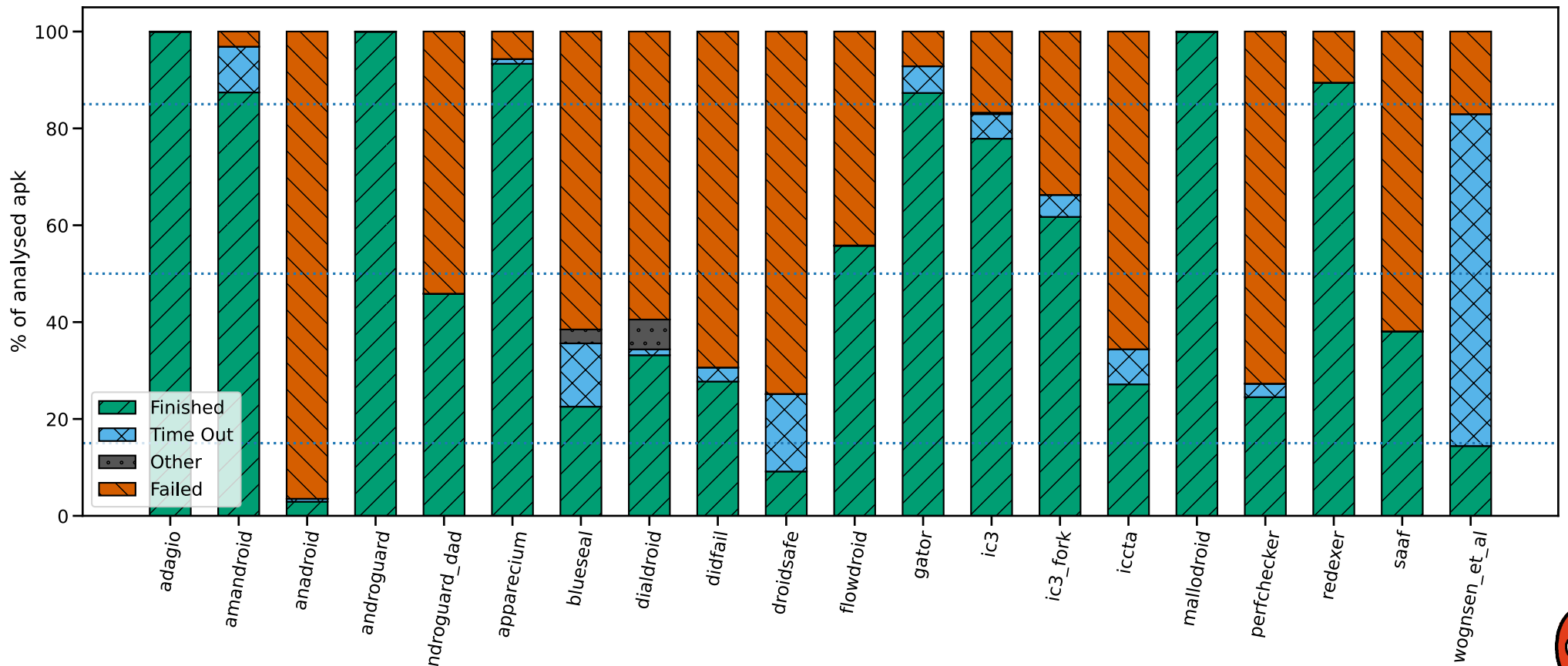
22 tools selected, 2 we could not package

Methodology: RASTA

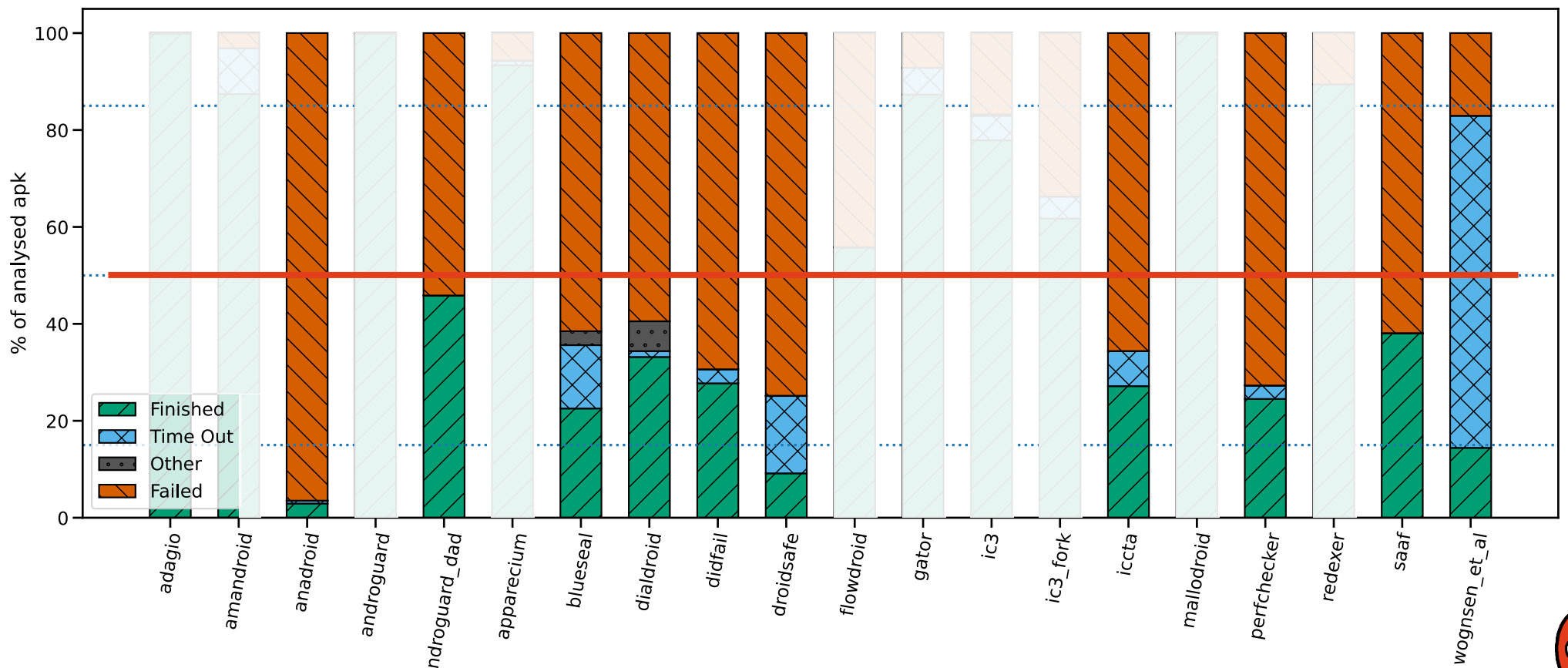


We check if the results **exist** after running a tool

Results


% of analysed apk
100
80
60
40
20
0
Finished
Time Out
Other
Failed
adagio
amandroid
anadroid
androguard
androguard_dad
apparecium
blueseal
dialdroid
didfail
droidsafe
flowdroid
gator
ic3
ic3_fork
iccta
mallodroid
perfchecker
redexer
saaf
wognsen_et_al

Results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flowdroid
gator
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ic3_fork
iccta
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PB1: Conclusion

Over **22** tools, **10 are usable**

International Conference on Software and Systems Reuse (ICSR 2024)

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Docker containers for tools **released**

International Conference on Software and Systems Reuse (ICSR 2024)

Class Shadowing

Class Loading

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State of the Art

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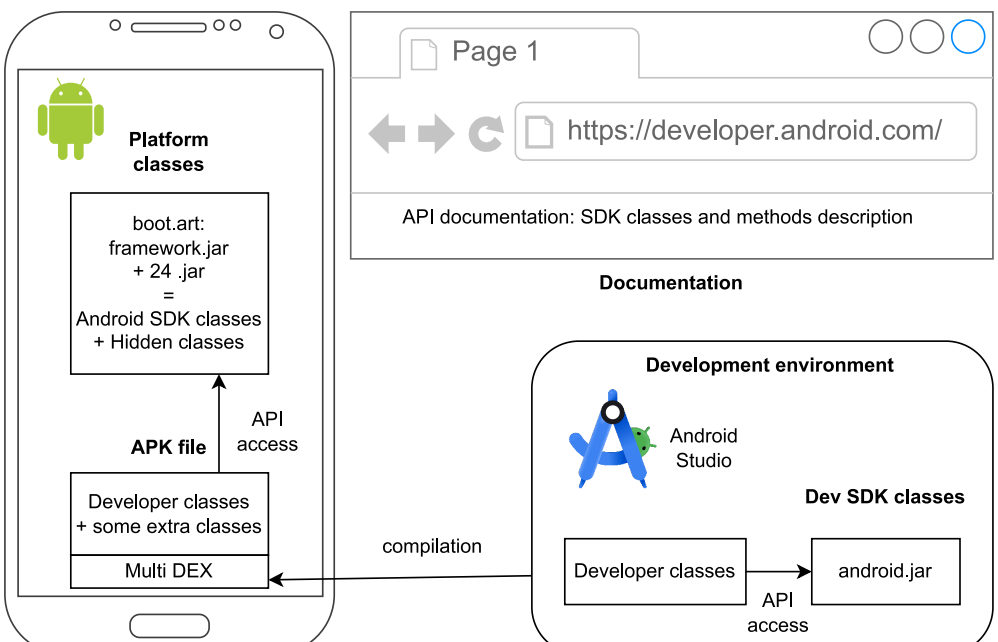
Android related contributions focus on Dynamic Code Loading (*e.g.* Zhang *et al.* 2015)

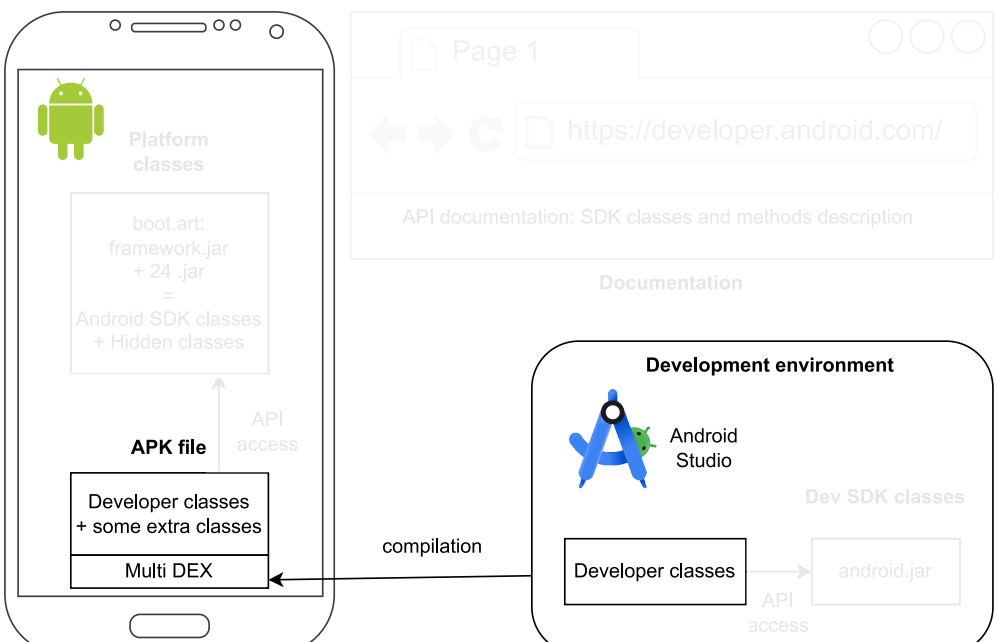
Android Ecosystem



Types of classes:

- APK Classes
- Platform Classes
  - SDK Classes
  - Hidden APIs

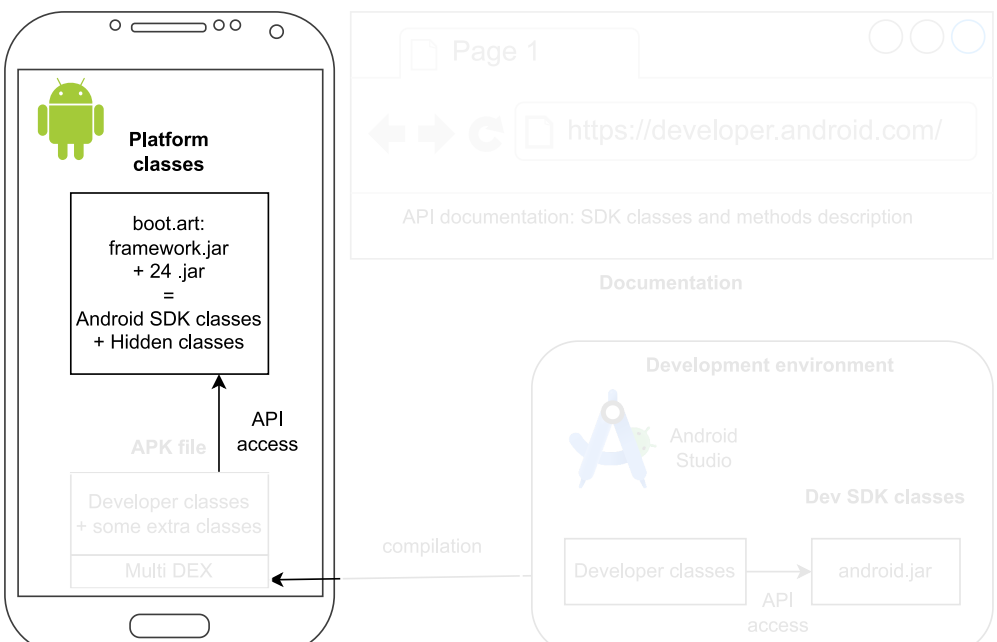
Android Ecosystem



Types of classes:

- **APK Classes**
- Platform Classes
  - SDK Classes
  - Hidden APIs

Android Ecosystem



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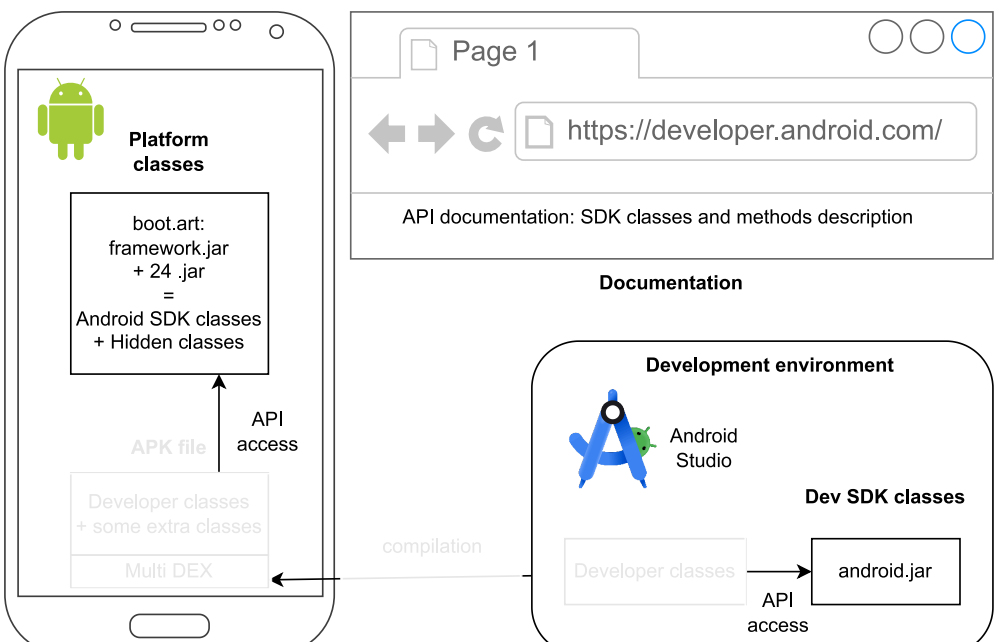

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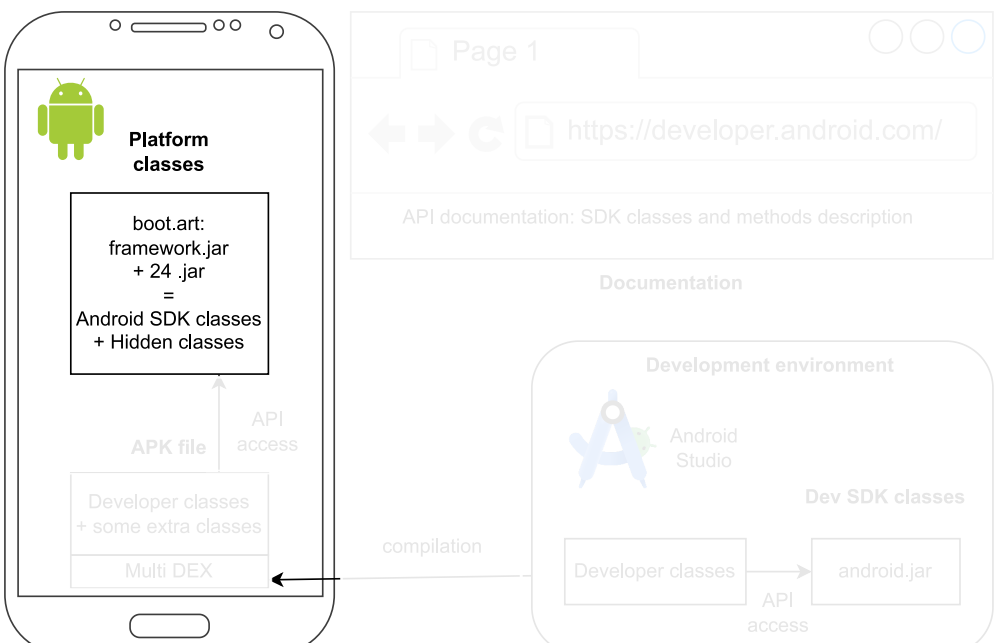

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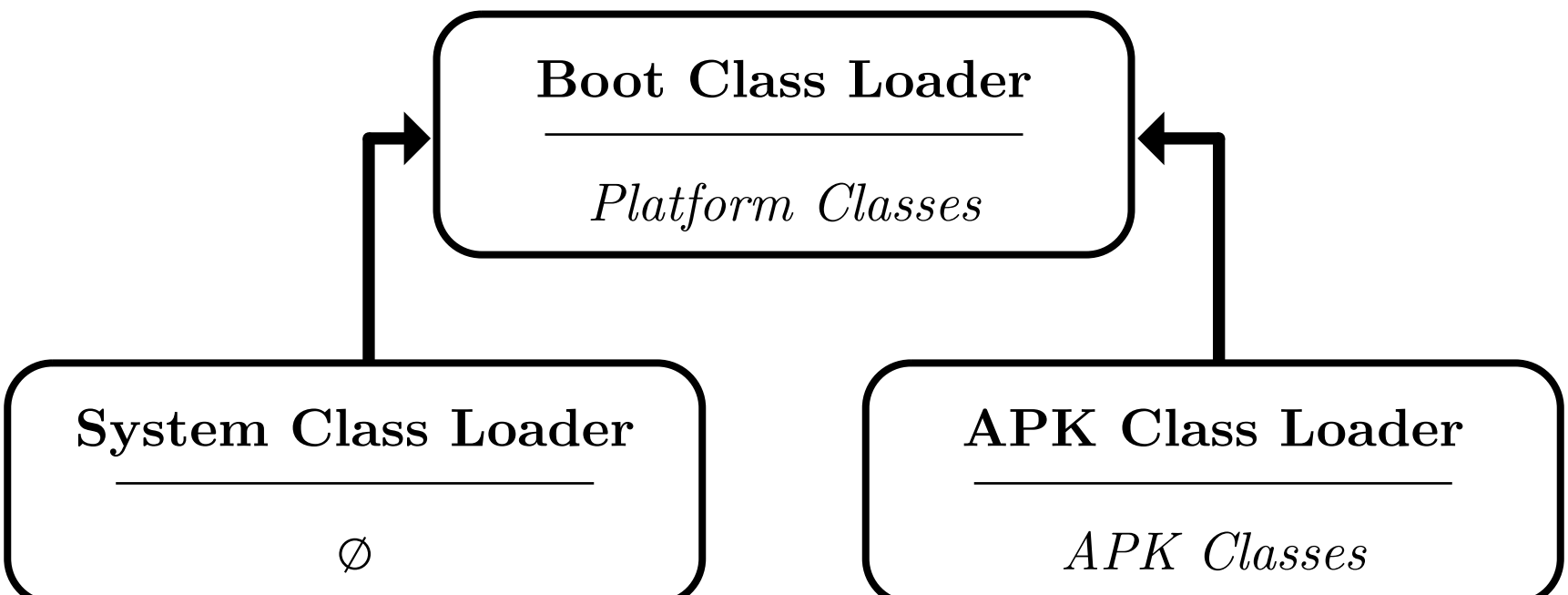
Android ClassLoaders



MultiDex

app.apk

```
AndroidManifest.xml
resources.arsc
META-INF/
res/
classes.dex
```

MultiDex

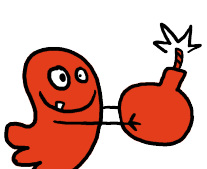
app.apk

```
AndroidManifest.xml     classes2.dex
resources.arsc          classes3.dex
META-INF/
res/
classes.dex
```

MultiDex

app.apk

```
AndroidManifest.xml     classes4.dex     classes11.dex
resources.arsc          classes5.dex     classes12.dex
META-INF/               classes6.dex     classes13.dex
res/                    classes7.dex     classes14.dex
classes.dex             classes8.dex     classes15.dex
classes2.dex            classes9.dex     classes16.dex
classes3.dex            classes10.dex    ...
```



MultiDex

app.apk

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AndroidManifest.xml
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META-INF/
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```

```
1 def get_dex_name(index: int):
2   if index == 0:
3     return "classes.dex"
4   else:
5     return f"classes{index+1}.dex"
```

Self-Shadowing

```
1 def get_dex_name(index:
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```

Android	Soot	Androguard⋆
classes.dex		
classes2.dex		
classes3.dex		
	...	
classes9.dex		
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~~classes1.dex~~		

⋆ estimation, non-deterministic

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	classes1.dex	
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	classes10.dex	
classes2.dex	classes2.dex	classes9.dex
classes3.dex	classes3.dex	classes8.dex
	…	
classes9.dex	classes9.dex	classes2.dex
classes10.dex		classes1.dex
~~classes1.dex~~		classes.dex

Shadow Attacks

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1  def get_dex_name(index: int):
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4    else:
5      return f"classes{index+1}.dex"
6  def load_class(class_name: str):
7    if is_platform_class(class_name):
8      return boot_cl.load(class_name)
9    else:
10     index = 0
11     dex_file = get_dex_name(index)
12     while exists_in_apk(dex_file) and \
13       class_name not in classes_of(dex_file):
14       index += 1
15       dex_file = get_dex_name(index)
16     if file_exists_in_apk(dex_file):
17       return load_from_file(dex_file, class_name)
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```

Android Class Loading Algorithm

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Impact on Tools

Tool	Version	Shadow Attack		
		Self	SDK	Hidden
Jadx	1.5.0	○	●	●
Apktool	2.9.3	○	●	●
Androguard	4.1.2	○	●	●
Flowdroid	2.13.0	●	×	●

●: attack sucessful
○: sucessful but producing warning or can be seen by the reverser
×: attack failed

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Flowdroid	×	×	●

Pull Requests:
soot/pull/2211 (merged)
jadx/pull/2702 (merged)
androguard/pull/1149

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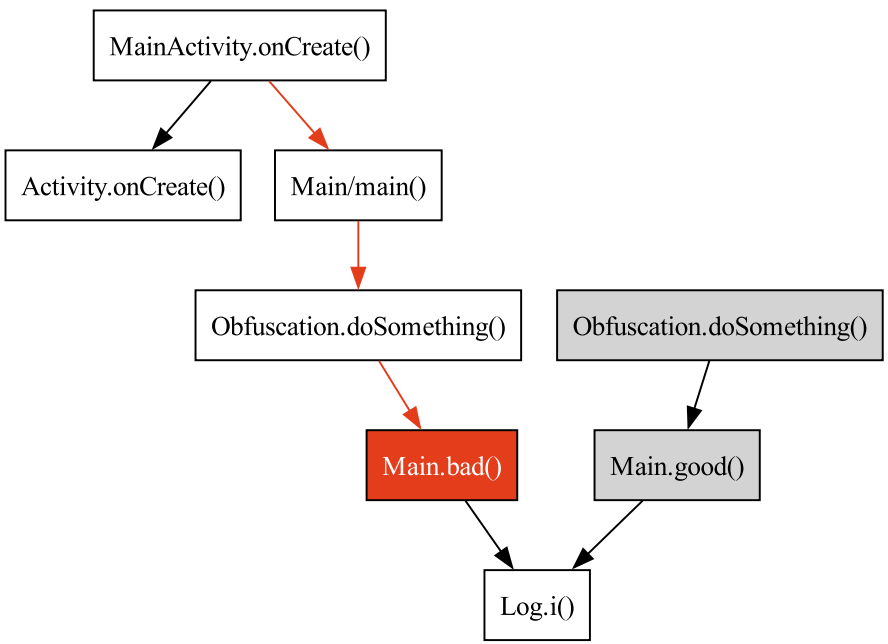
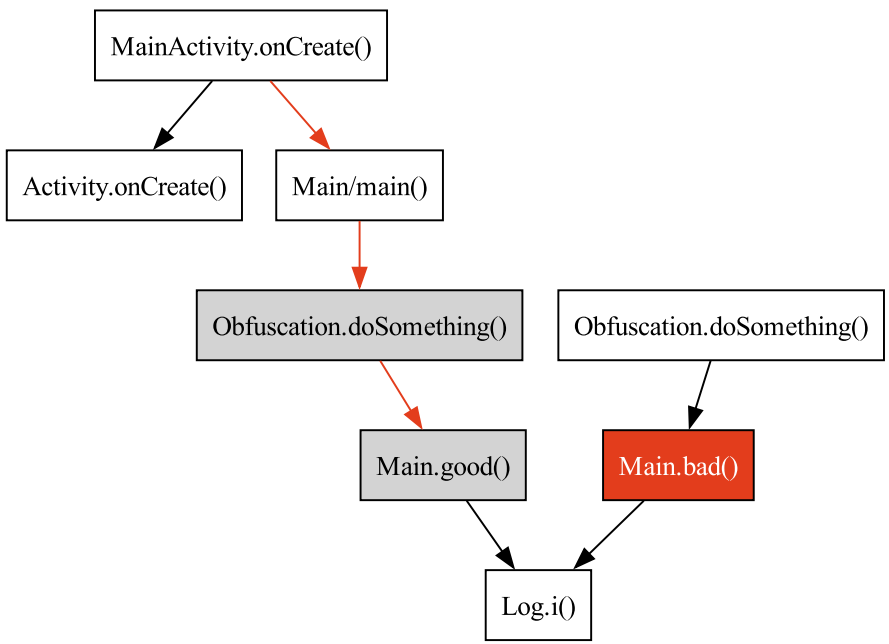
Androguard on Toy Malware



Expected



Computed

In the Wild: 49 975 APKs

	Number of apps			Nb Shadow Classes		Identical Code
		%	% malware	Average	Median	
Self	234	0.47%	5.98%	438.1	18	74.8%
Sdk	11 755	23.52%	0.38%	27.6	5	8.04%
Hidden	1556	3.11%	0.71%	16.1	1	17.42%
Total	12 301	24.61%	0.42%	36.7	6	23.76%

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We modeled the class loading algorithm

Digital Threats: Research and Practice, vol. 6 (3), 2025

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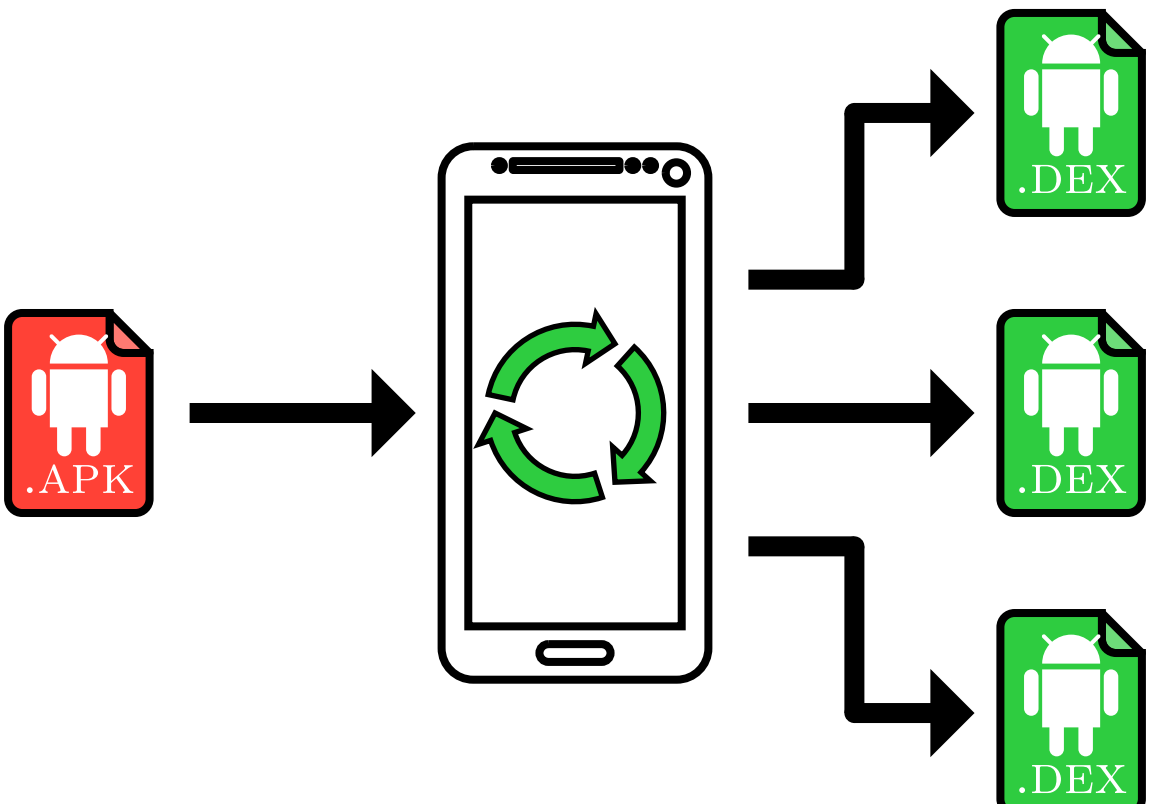
Ambiguous cases exist in the wild

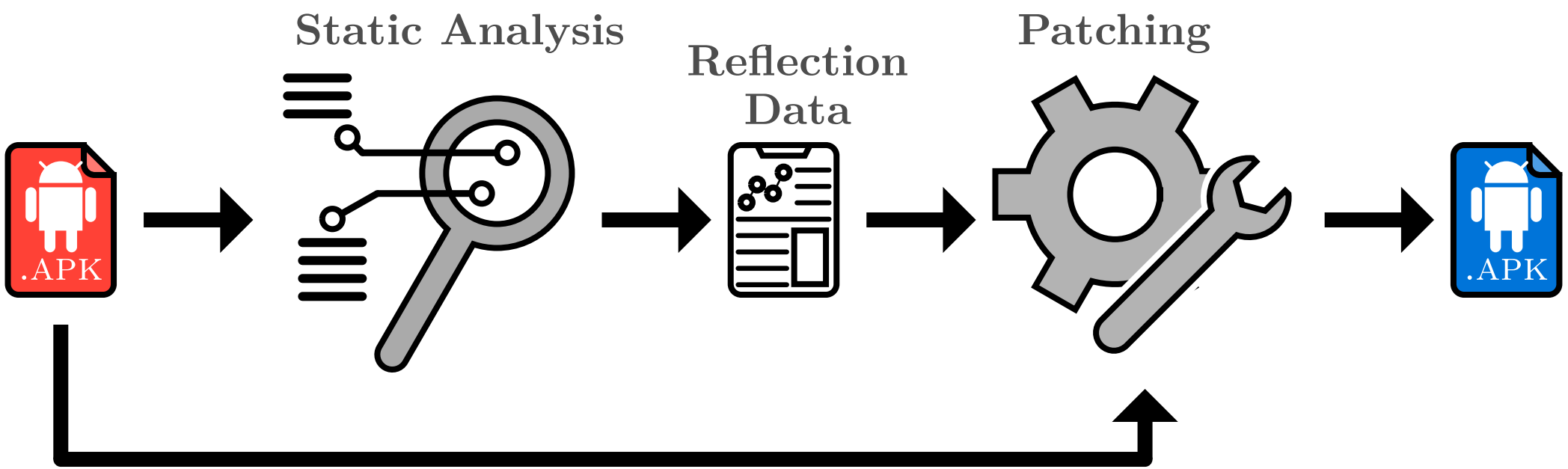
Digital Threats: Research and Practice, vol. 6 (3), 2025

The Application of Theseus

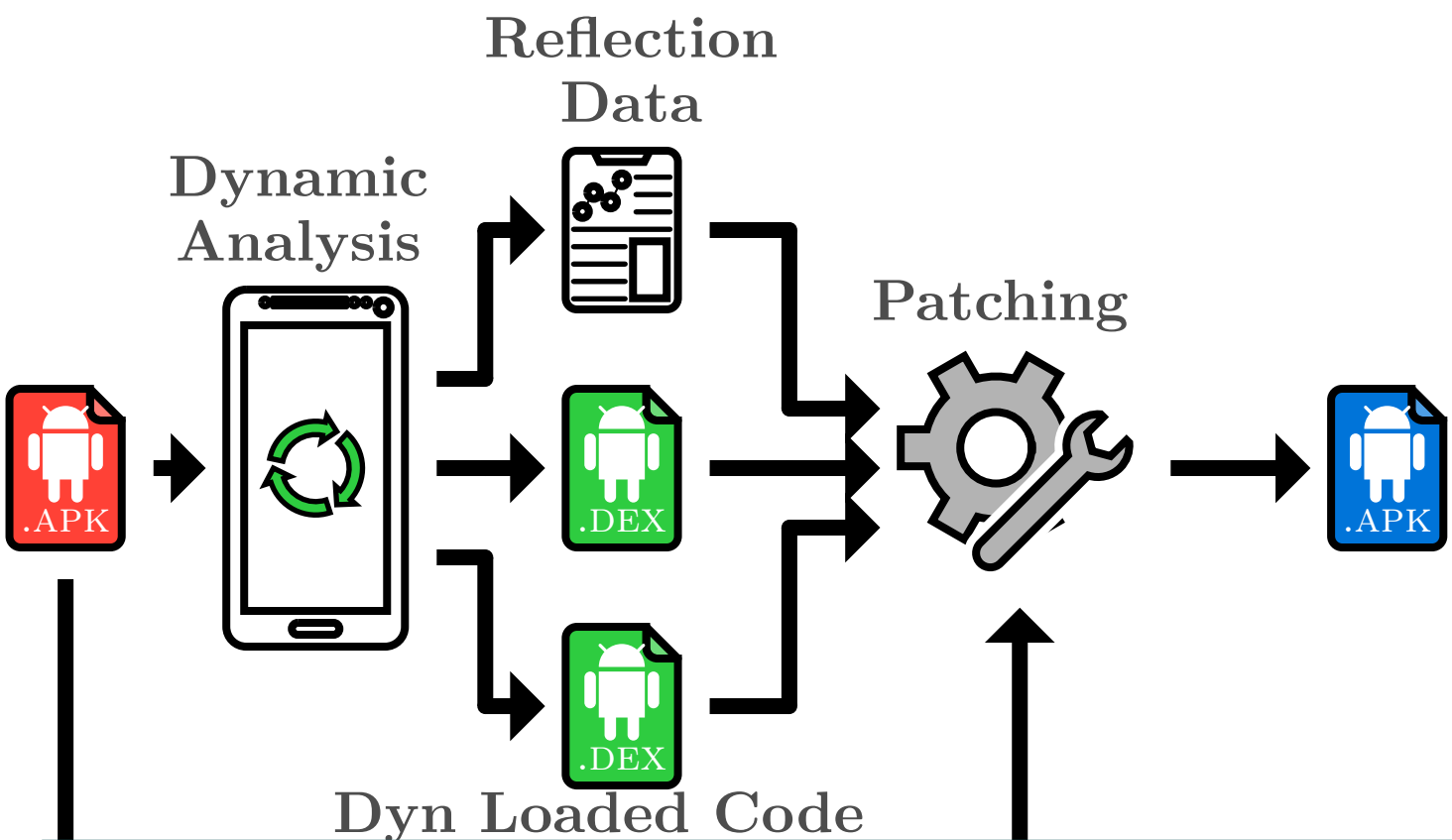
Dexhunter: Zang *et al.* (2015)



DroidRA: Li *et al.* (2016)



Theseus: Overview



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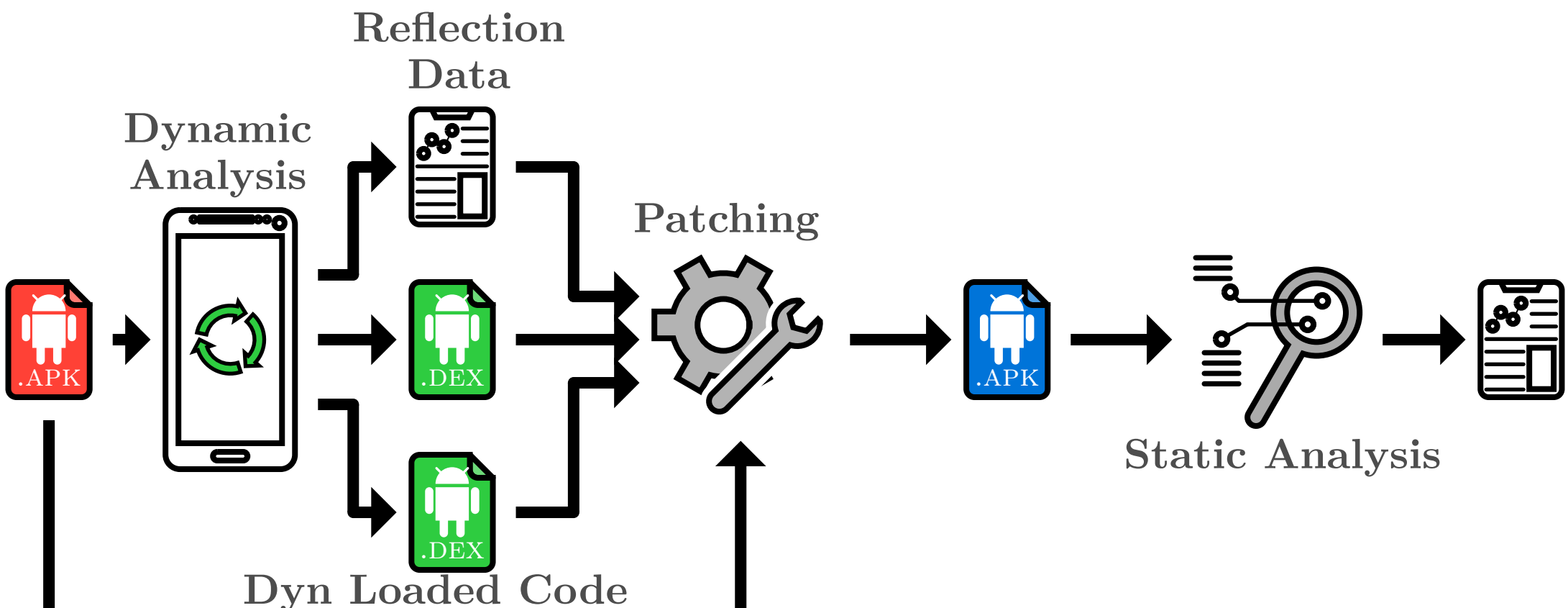

Dynamic Analysis

Frida: intercepts method calls

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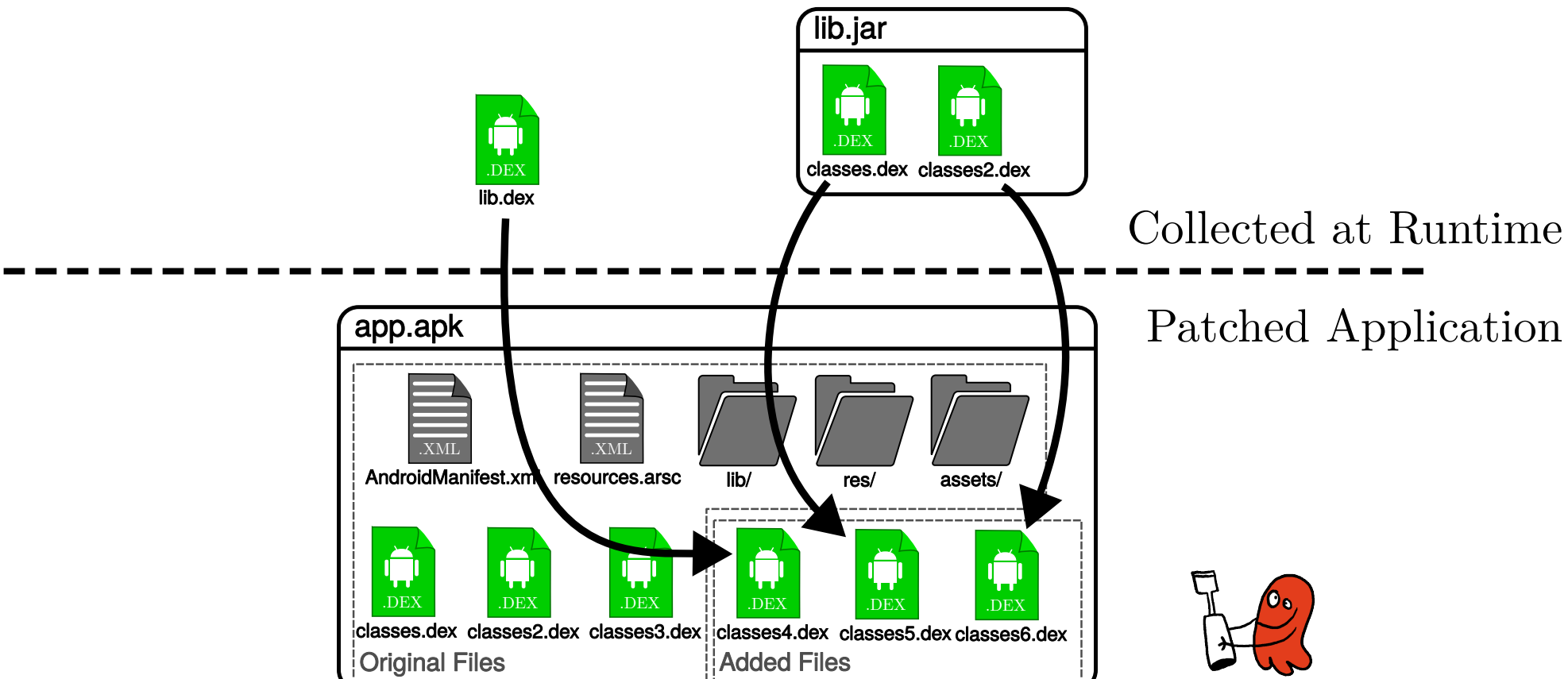
Android Emulator: runs on computer/server

Grodd Runner: clicks buttons (Abraham *et al.*, 2015)

Phone with adb enable: actual hardware

Human: intelligent button clicker

Transformation: Dynamic Code Loading



Reflection Transformation

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5  Method mth = getMethod();
6  String retData = (String) mth.invoke(obj, args);
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```
6  String retData = obj.myMethod((String)args[0]);
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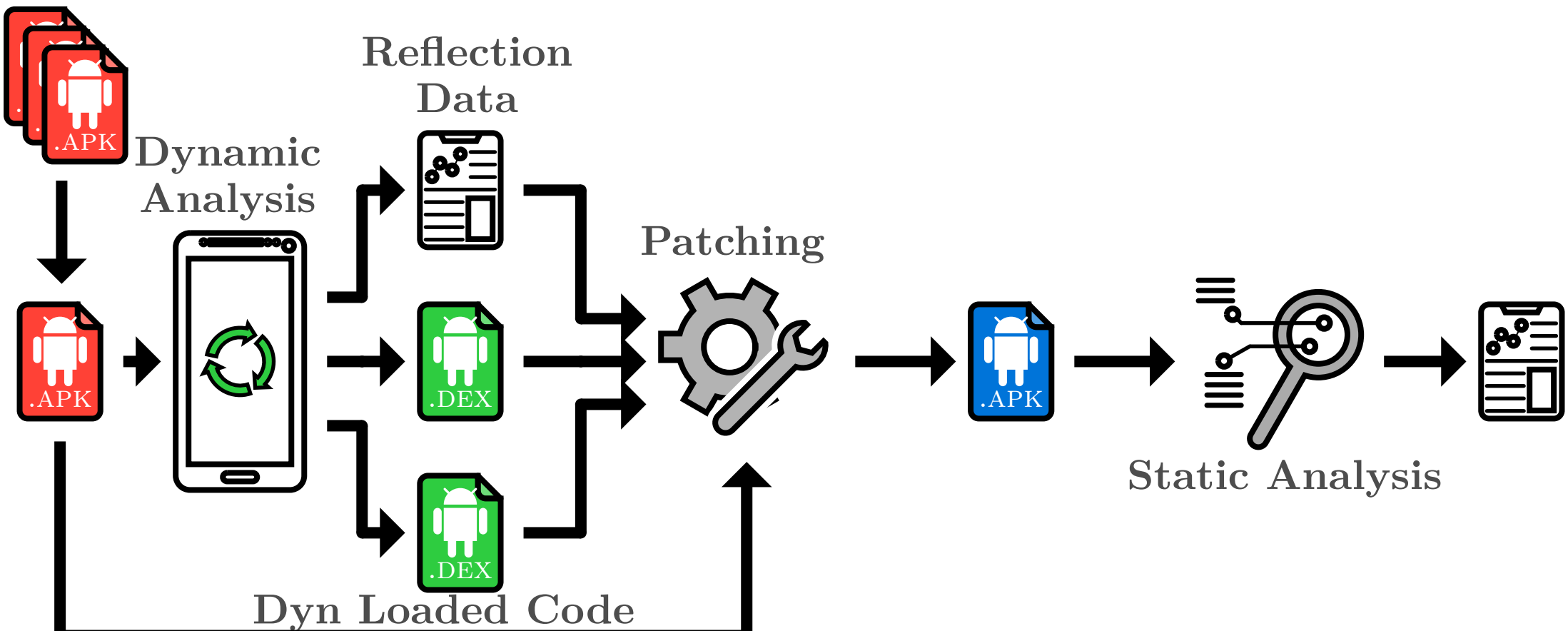
RASTA


.APK
Dynamic Analysis
Reflection Data
.APK
.DEX
.DEX
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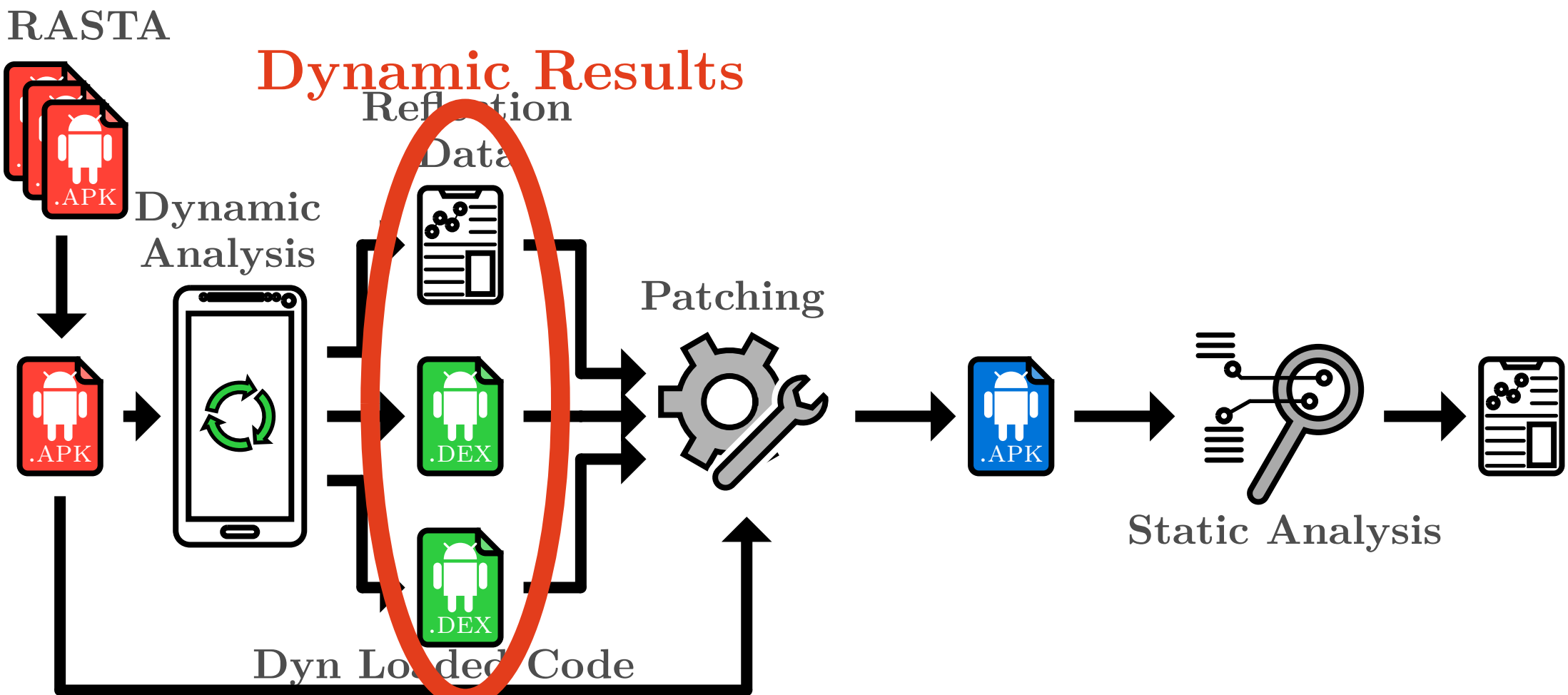
Patching
.APK
Static Analysis


RASTA
Dynamic Results
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Dynamic Analysis

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With Code Loading	598	453	145

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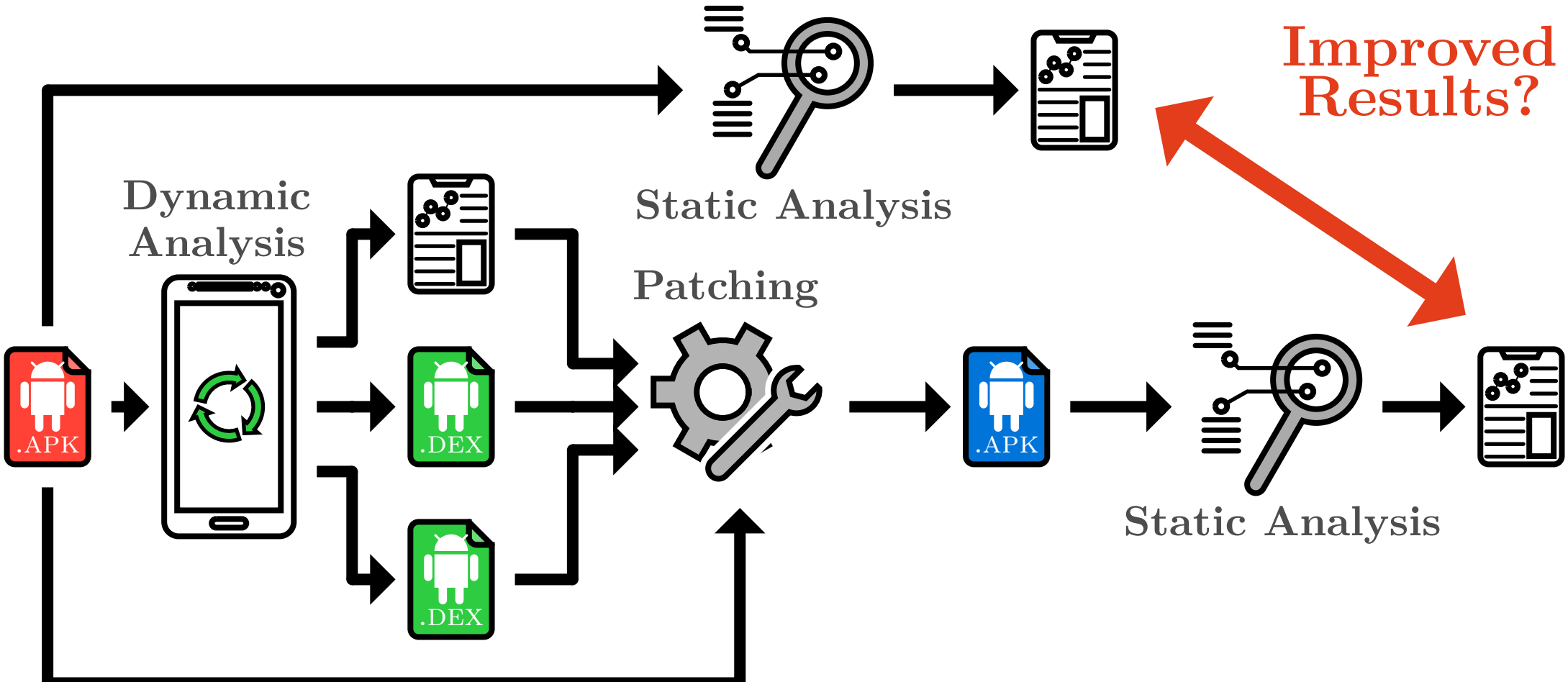
Reflection detected on **79.64%** of APKs tested

DLC detected on **12.06%** of APKs tested

Collected Bytecode

Nb Occurences	SHA 256	Content	Format
273	bee390afa2...	Lcom/facebook/ads/*	DEX
98	7aae06433c...	Lcom/facebook/ads/*	DEX
70	920e465a87...	Lcom/facebook/ads/*	DEX
31	51dd5ff34a...	Lcom/google/android/ads/*	APK
12	d44cfb6b41...	Lcom/google/android/ads/*	APK
9	be87bb0a50...	Lcom/facebook/ads/*	DEX
9	26fb1a7903...	Lcom/facebook/ads/*	DEX
7	8395a0121e...	Lcom/facebook/ads/*	DEX
7	1eea5584eb...	Lcom/google/android/ads/*	APK
6	94f66aa1ae...	Lcom/appsflyer/internal/*	DEX
	...		


Improved Results?
Static Analysis
Dynamic Analysis
Patching
.APK
.DEX
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.APK
Static Analysis

Added Method Calls

APK SHA 256	Number of Call Graph edges	
	Diff (Total After - Before)	Replaced Reflection
0019d7fb6a...	59 529	1
274b677449...	3061	26
34599c2499...	2876	29
35065c6834...	3449	26
e7b2fb02ff...	747	91
efececc03c...	278	23
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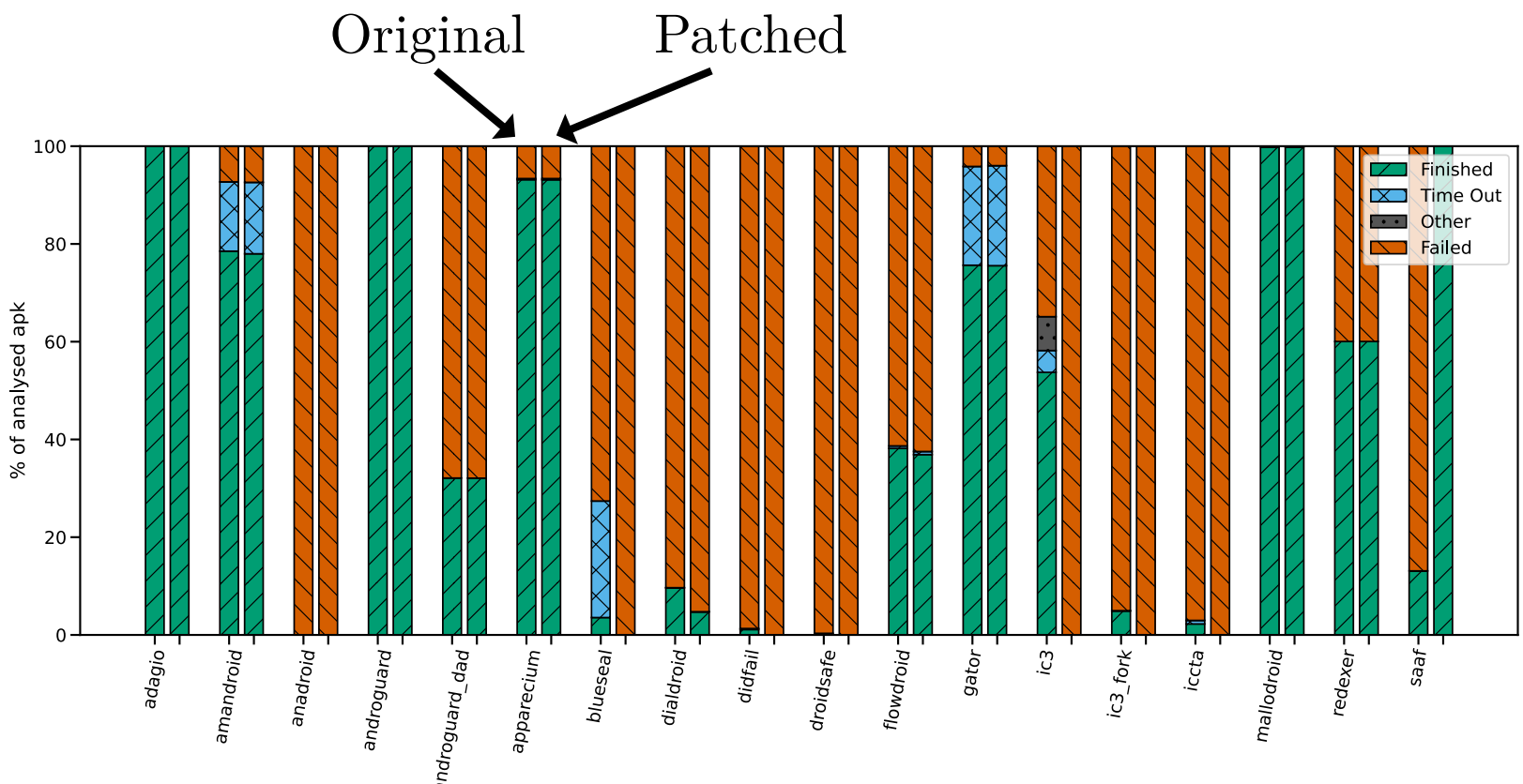
Impact on Finishing Rate



PB3: Conclusion

We can statically **analyse APKs with reflection and dynamic code loading** with our method

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Software Contributions:

Androscalpel: rust crate to **parse, modify and generate bytecode**

Theseus: tool implementing the method presented here

Conclusion

Experimentations

	Experiment	Number of APKs	Time
RASTA	20 static analyses	62 525	2 months
Class Loading	1 static analysis	49 975	1 week
Theseus	1 dynamic analysis	4957	1 week
	patching	4748	2 days
	18 static analyses	8955	2 months

We showed that:

Most Static analysis tools are no longer usable after a few years. The size of the application seems to be the most significant factor.

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Android behaviour is complex and not well known. In the specific case of class loading, we showed that state-of-the-art tools do not match Android, leading to invalid analyses.

APKs can be augmented with instrumentation to improve further analyses with any other tools.

We showed that:

Most Static analysis tools are no longer usable after a few years. The size of the application seems to be the most significant factor.

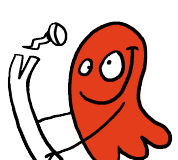
Android behaviour is complex and not well known. In the specific case of class loading, we showed that state-of-the-art tools do not match Android, leading to invalid analyses.

APKs can be augmented with instrumentation to improve further analyses with any other tools.

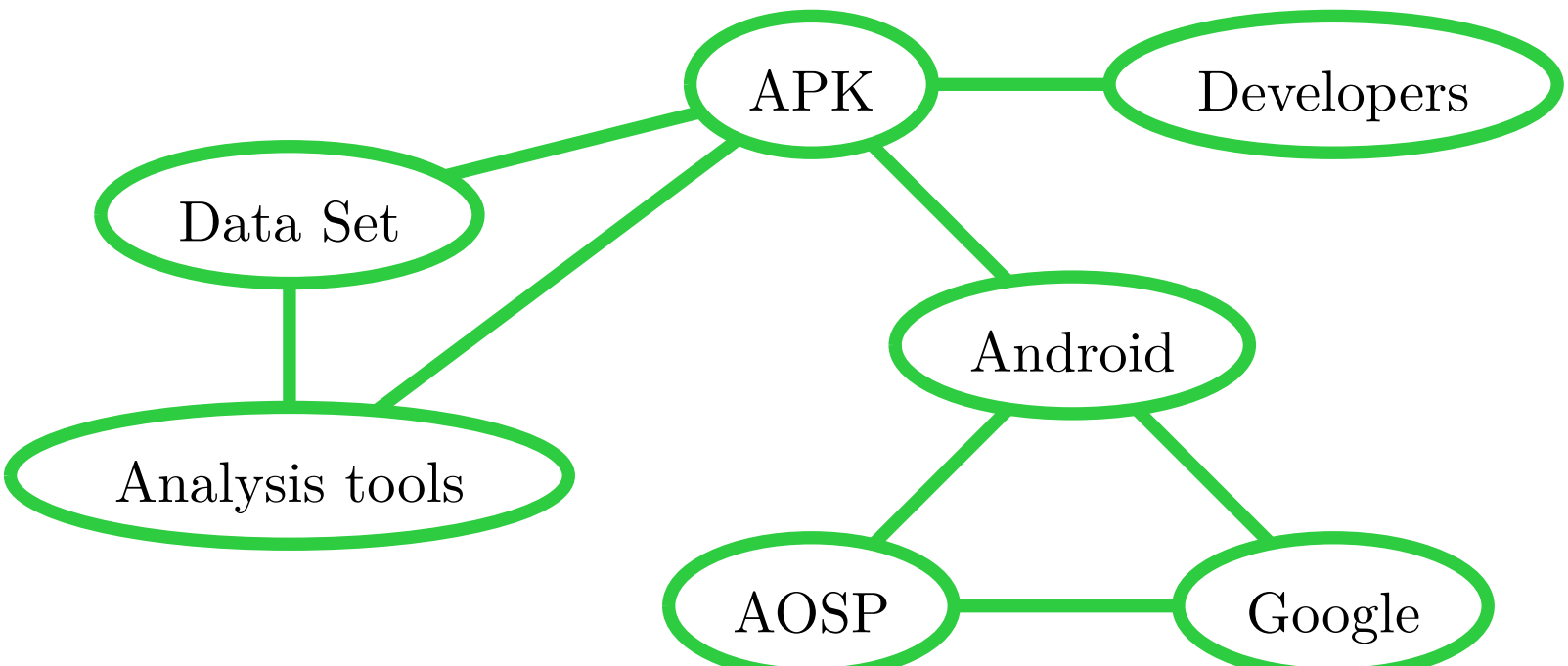
Also, dynamic analysis is still very much not trivial.

Future Works

A lot of engineering, preferably spearheaded by Google.



Future Works



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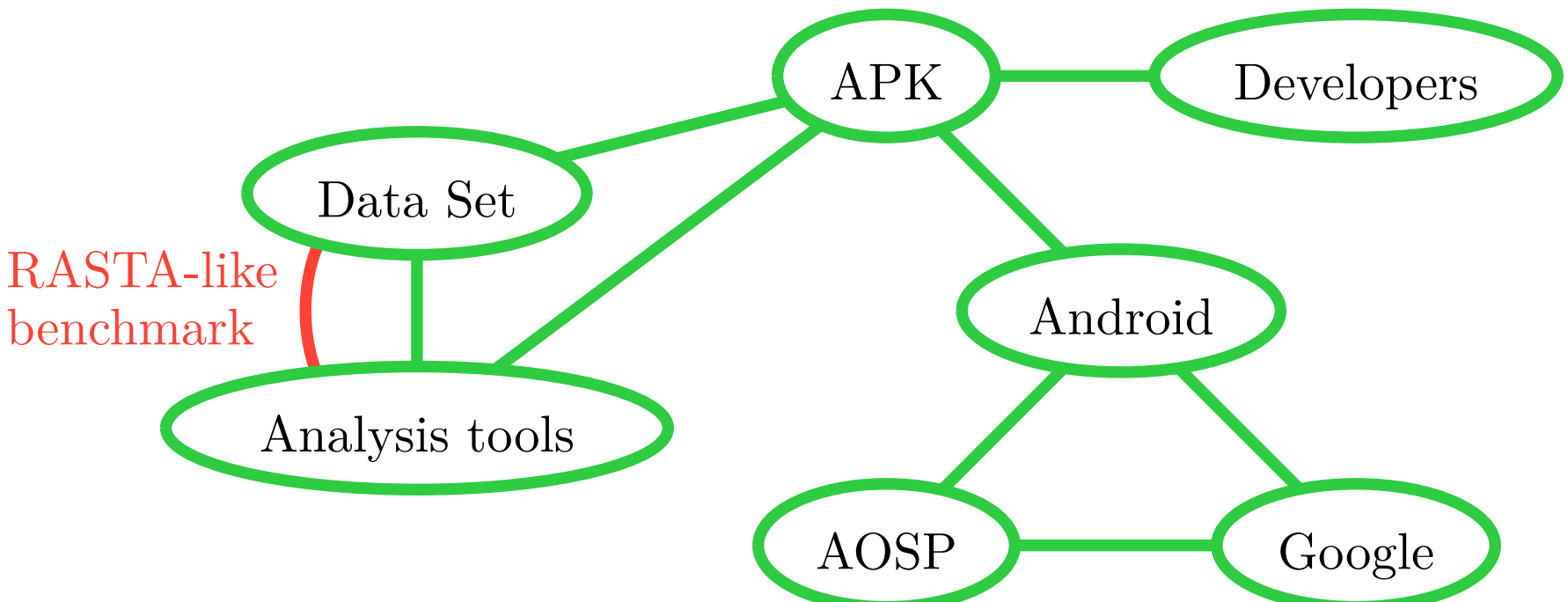
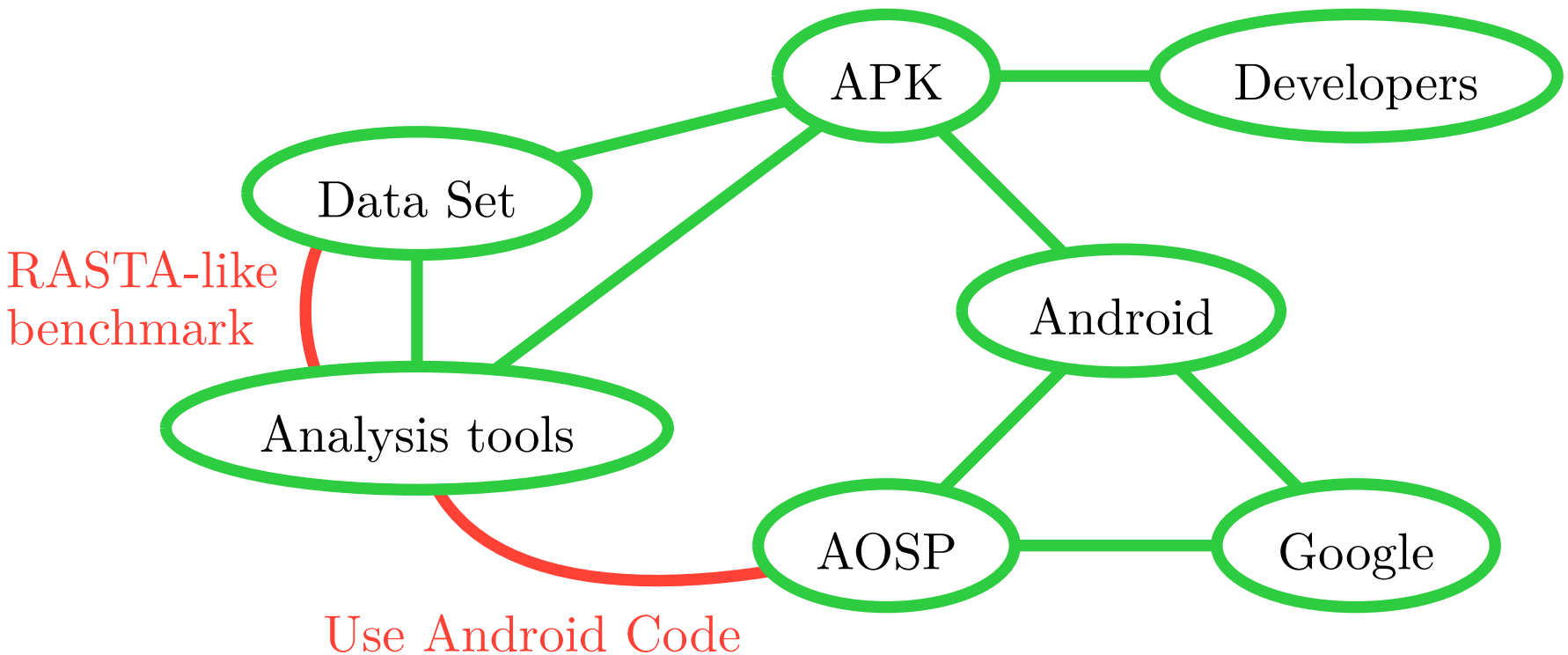
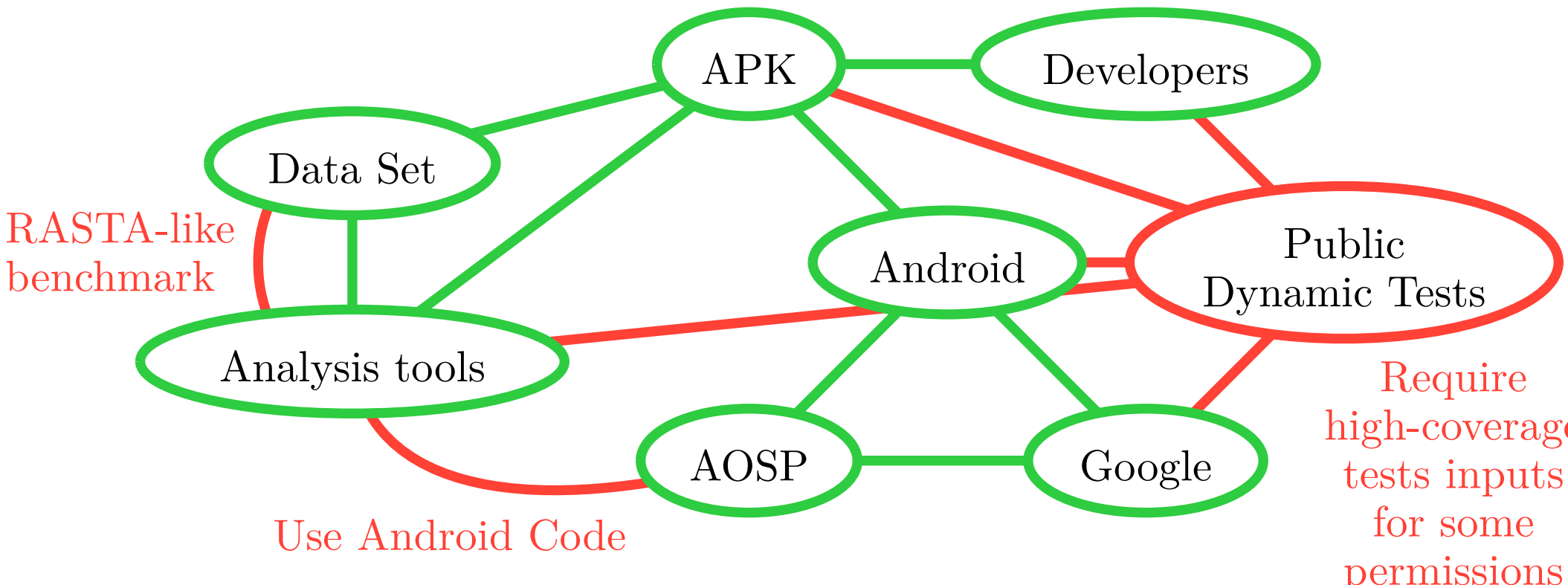


Future Works



Future Works



Questions

Bibliography