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Malton: Towards On-Device Non-Invasive Mobile Malware Analysis for ART

Lei Xue[1], Yajin Zhou, Ting Chen[1], Xiapu Luo[1], Guofei Gu[2]

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The Hong Kong Polytechnic University

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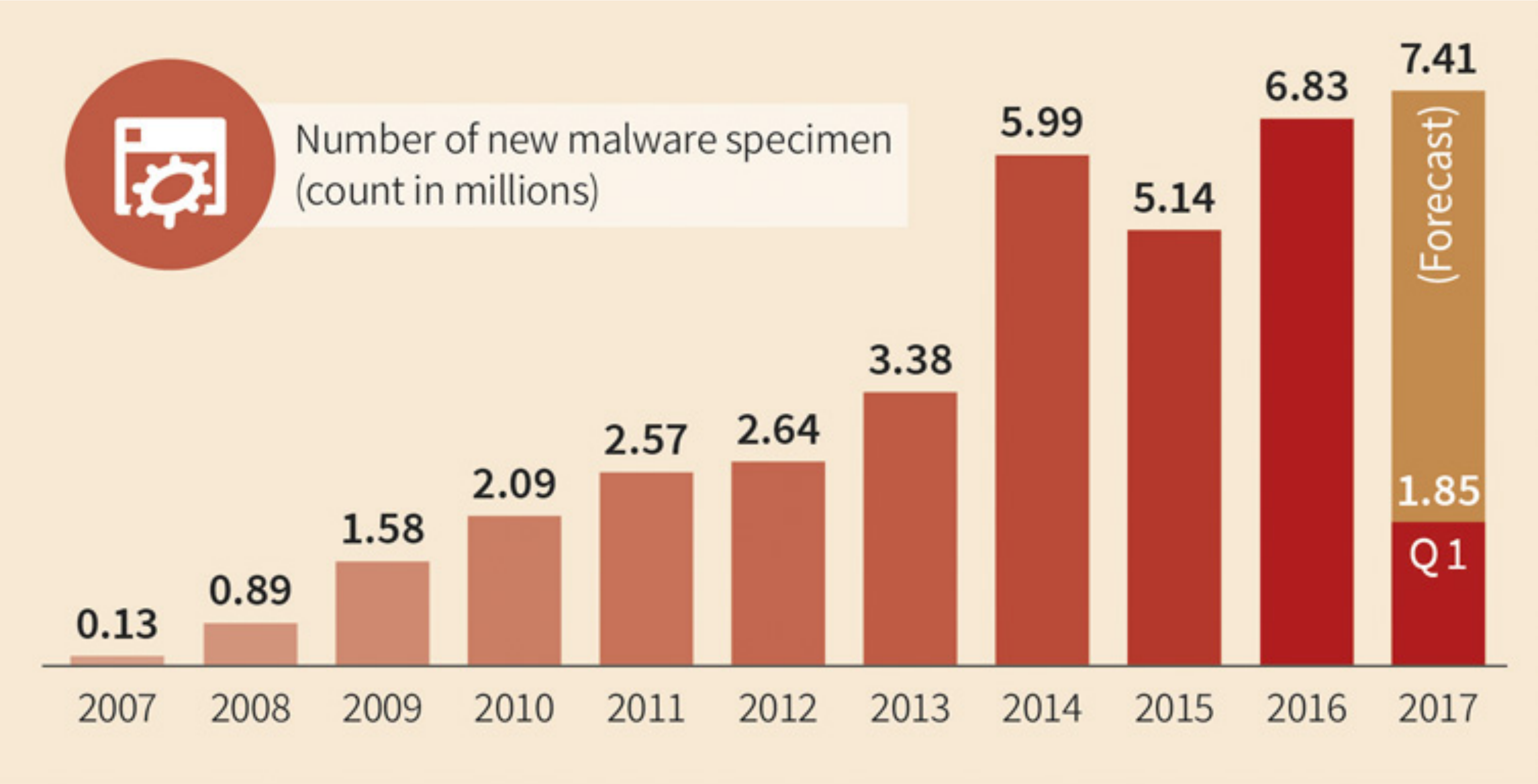
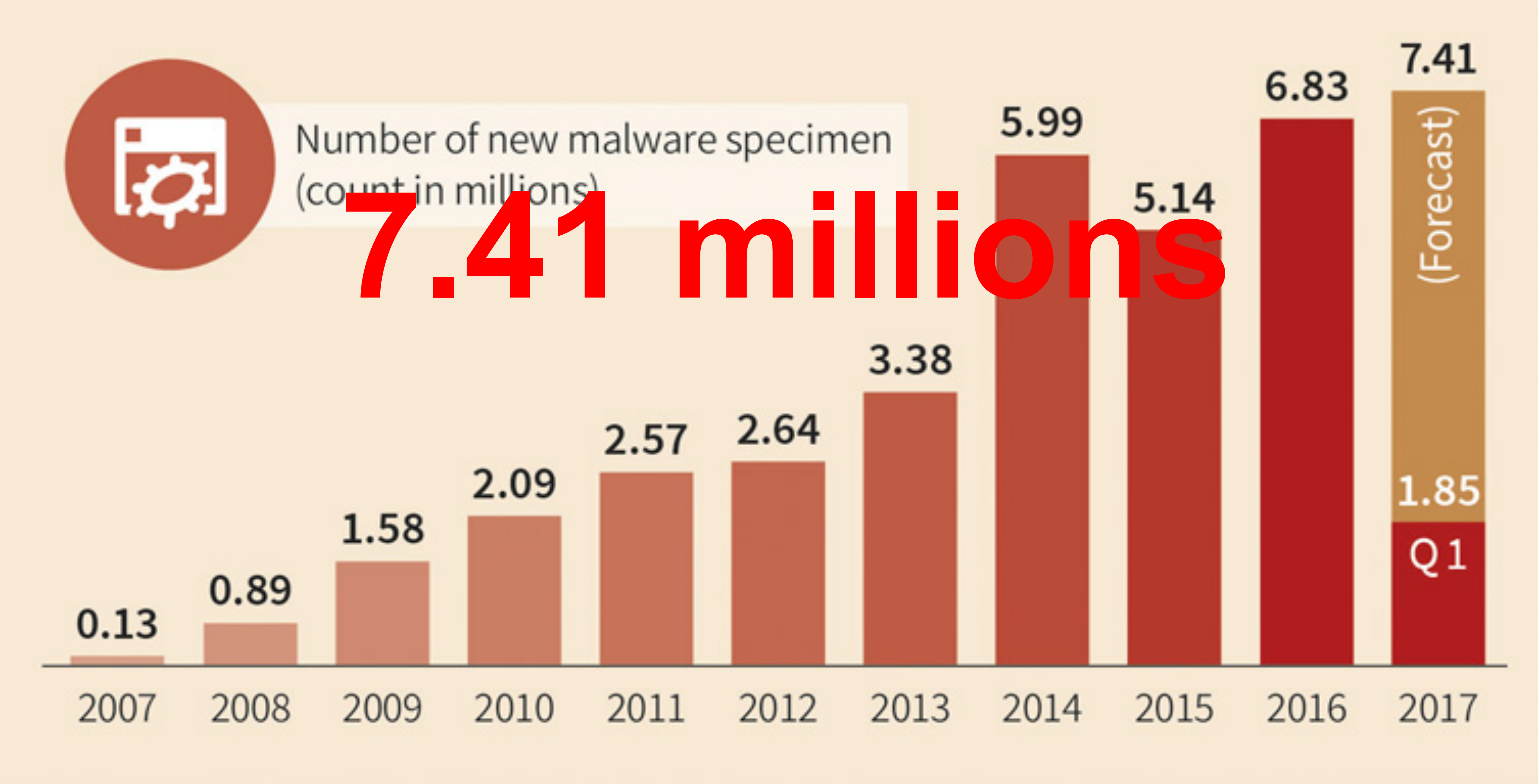
Texas A&M University



https://www.gdatasoftware.com/blog/2017/04/29666-malware-trends-2017



7.41 millions

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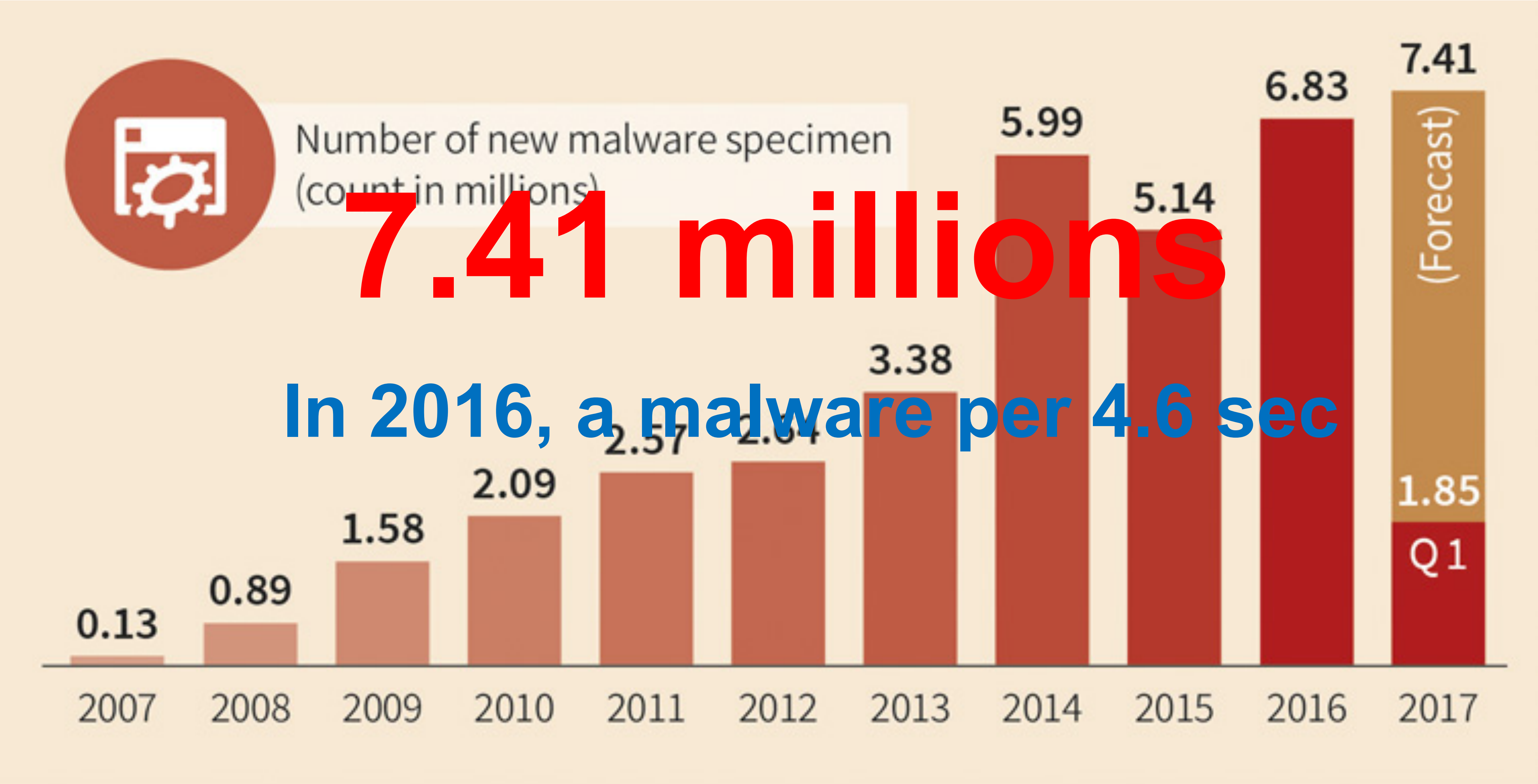

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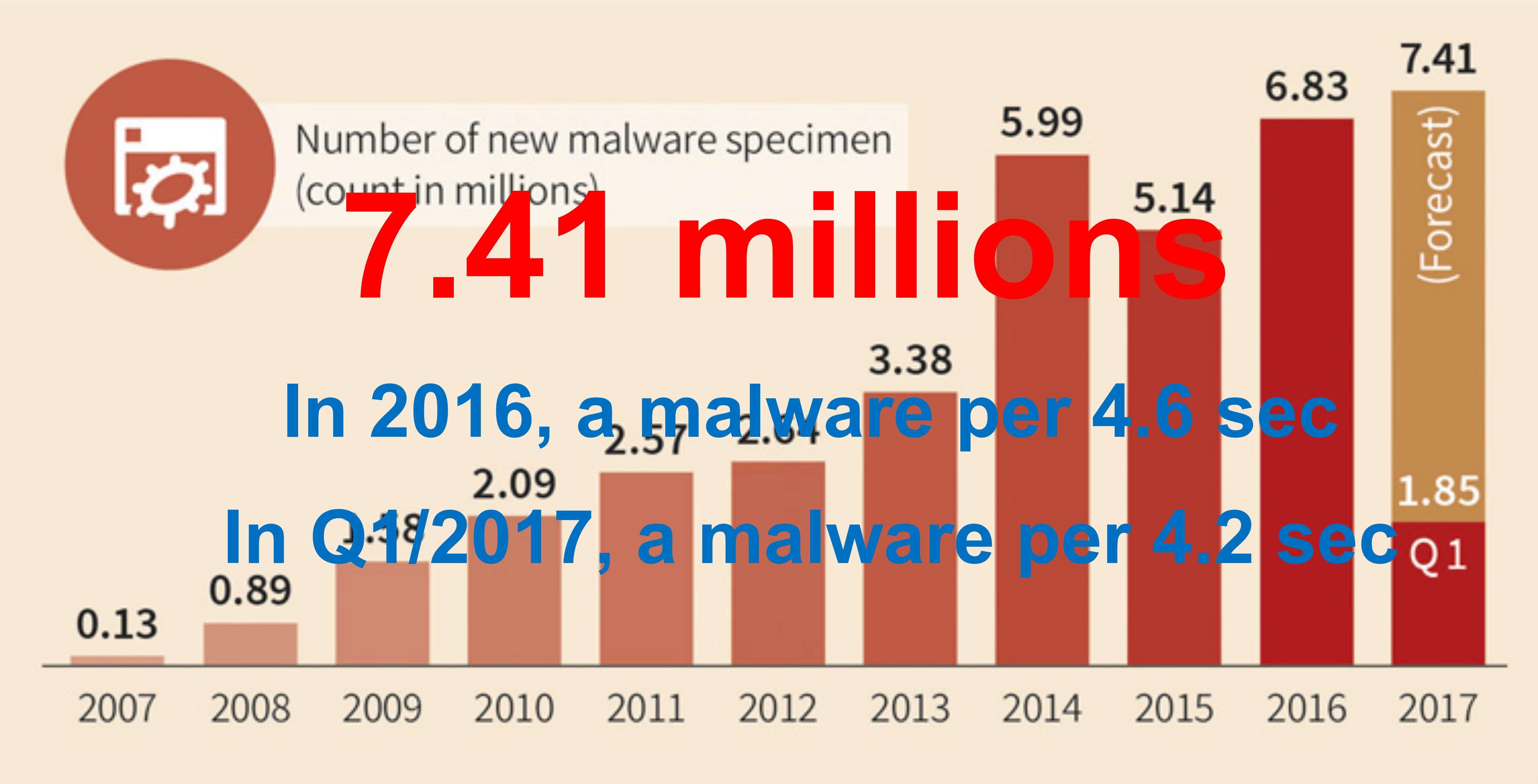

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In Q1/2017, a malware per 4.2 sec

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e.g., DroidBox (Android framework layer), DroidTrace (System layer)

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e.g., TaindDroid (DVM), TaintART, ARTist (dex2oat of ART)

4 **Modify the target apps**

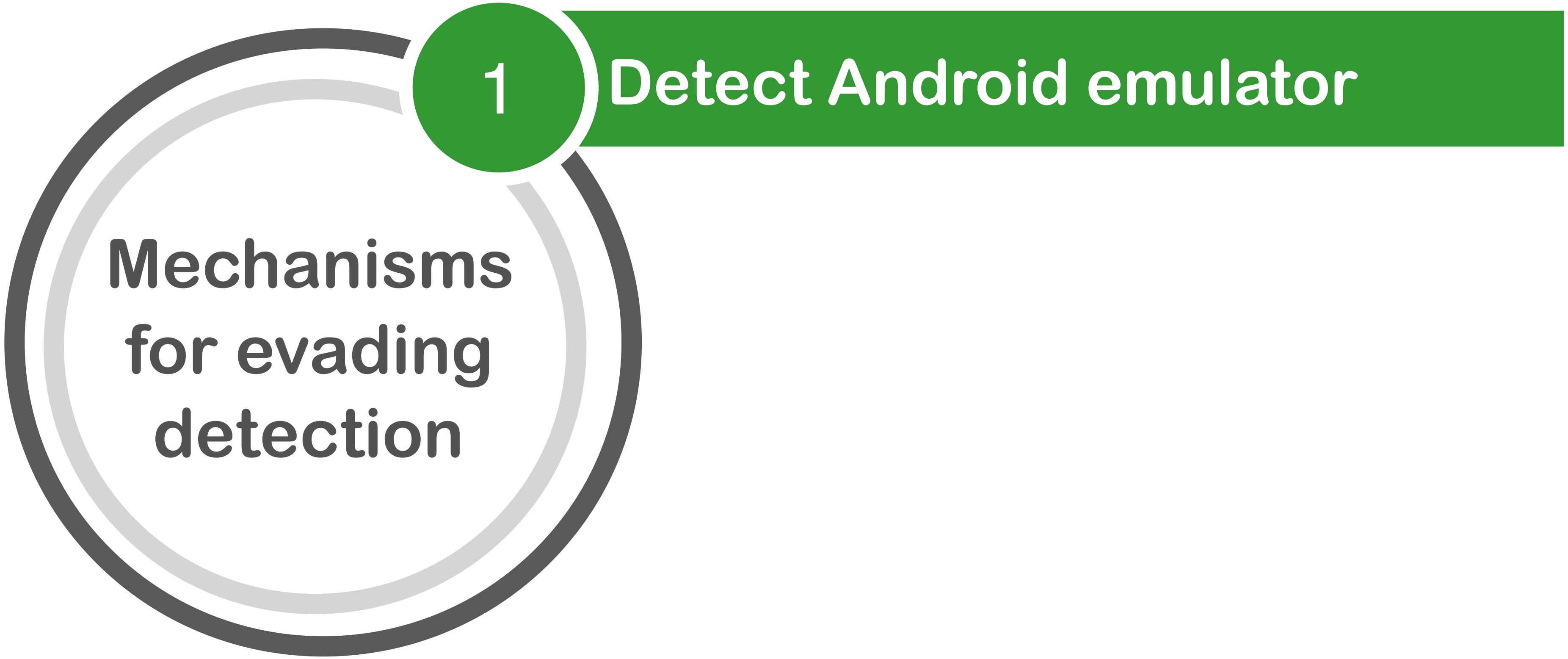
e.g., Aurasium

Malware

Malware

Mechanisms for evading detection

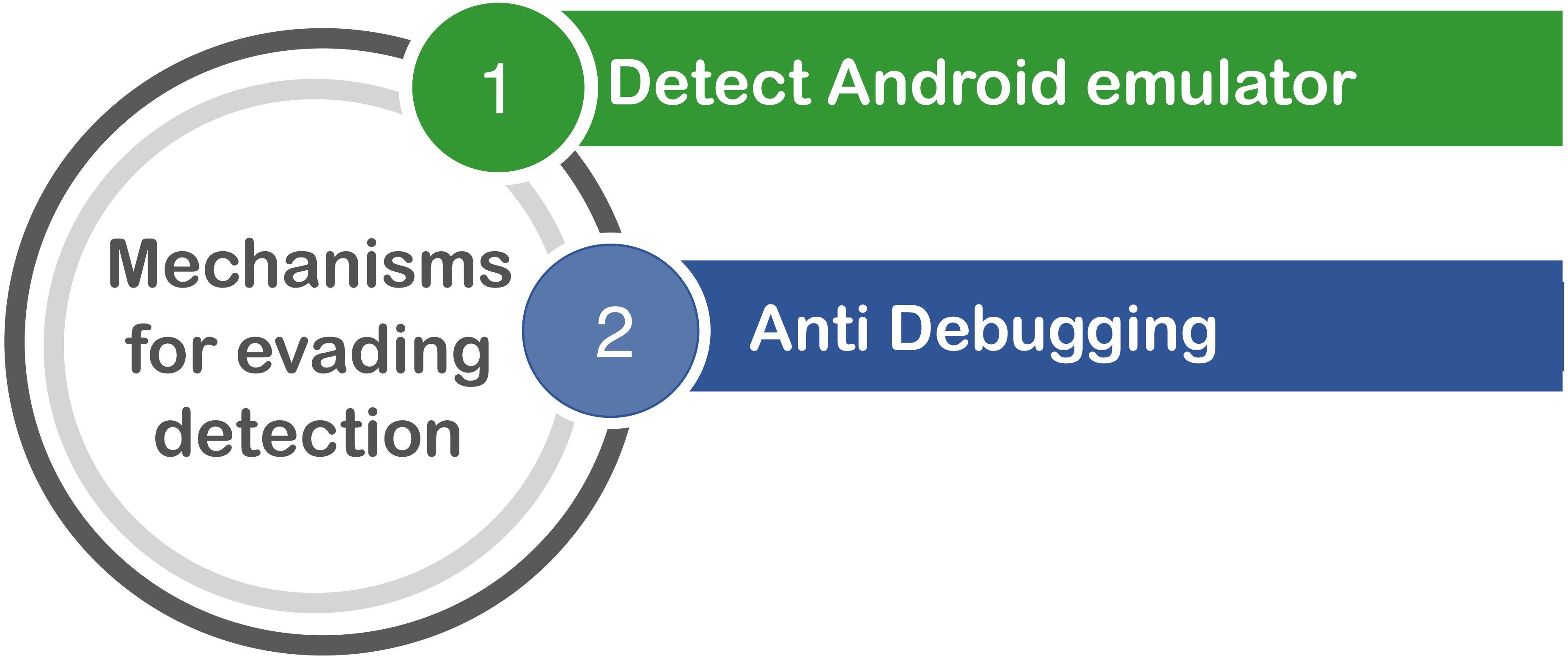
Malware



Mechanisms for evading detection

1 Detect Android emulator

Malware



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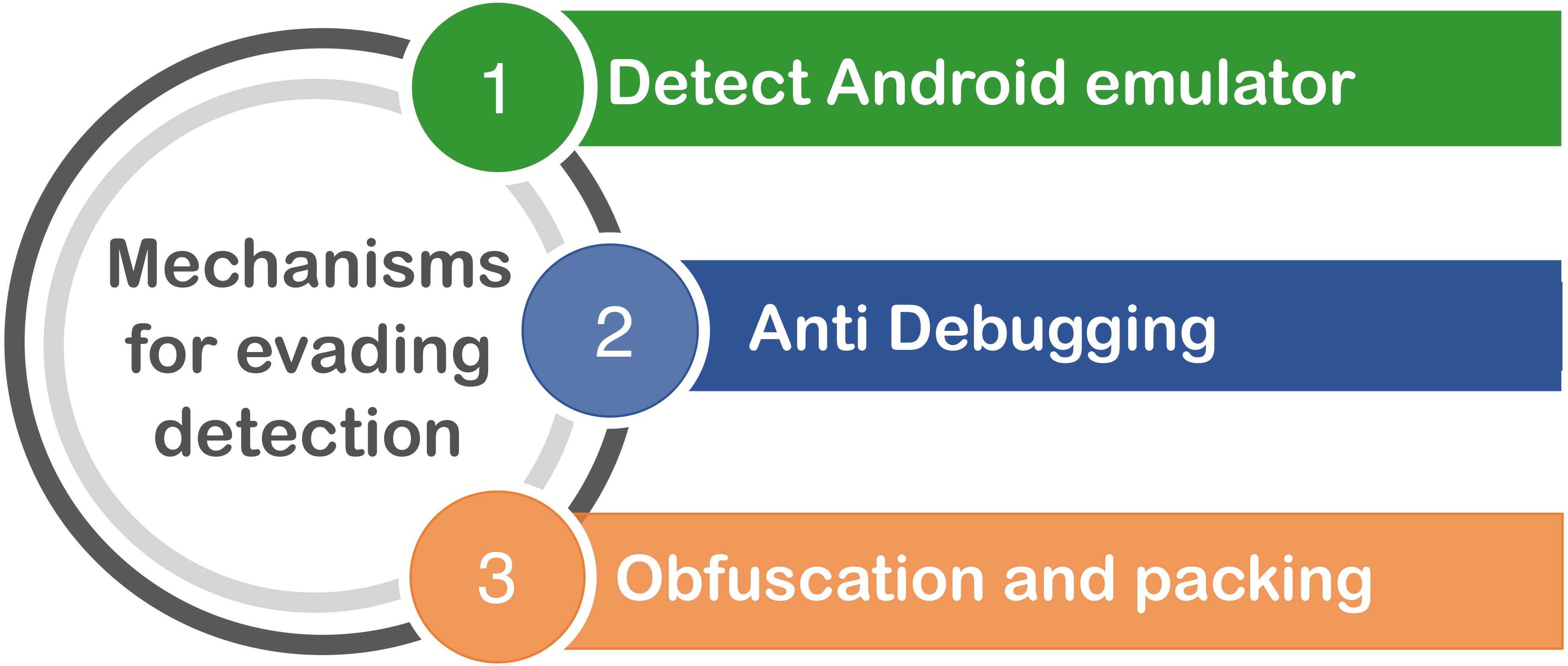

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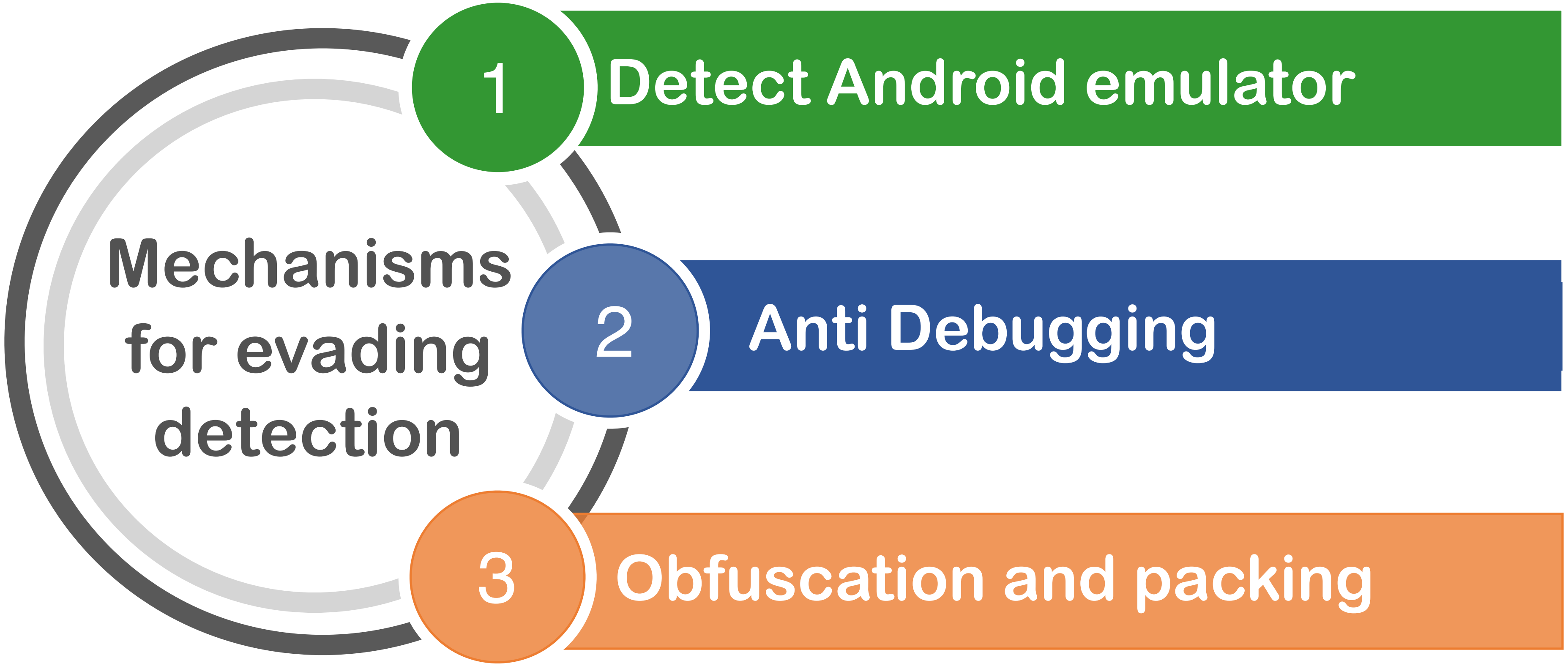

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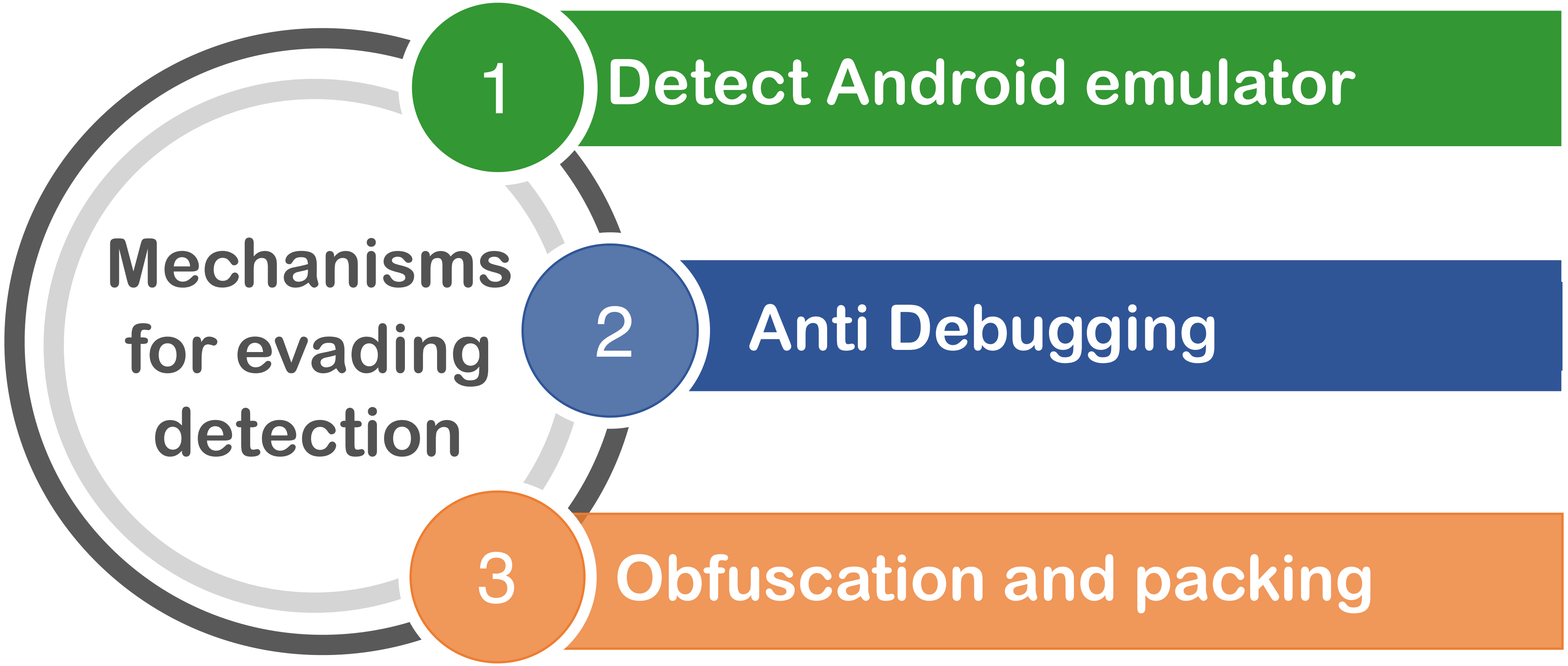

Mechanisms for evading detection

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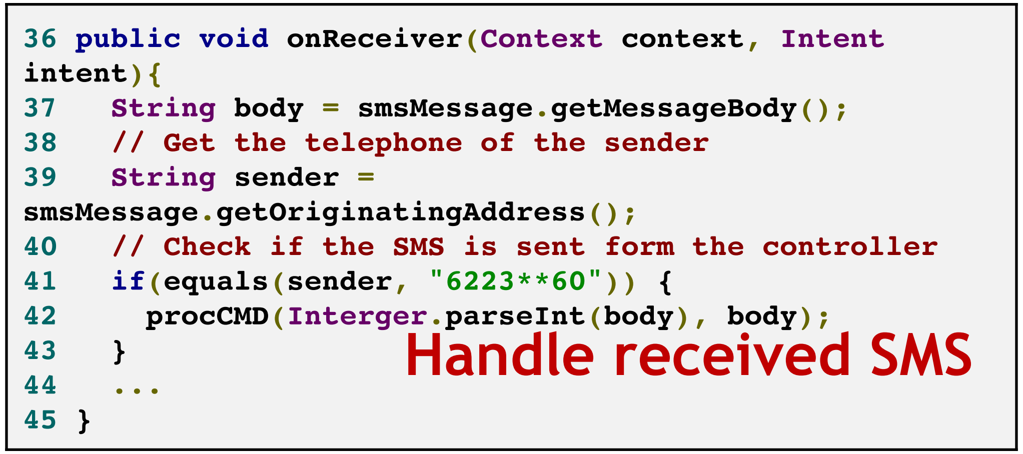
Malton On-device and Non-invasive Analysis for ART

Agenda

- ❑ Motivating Example
- ❑ The New Android Runtime (ART)
- ❑ Malton
- ❑ Evaluation
- ❑ Conclusion

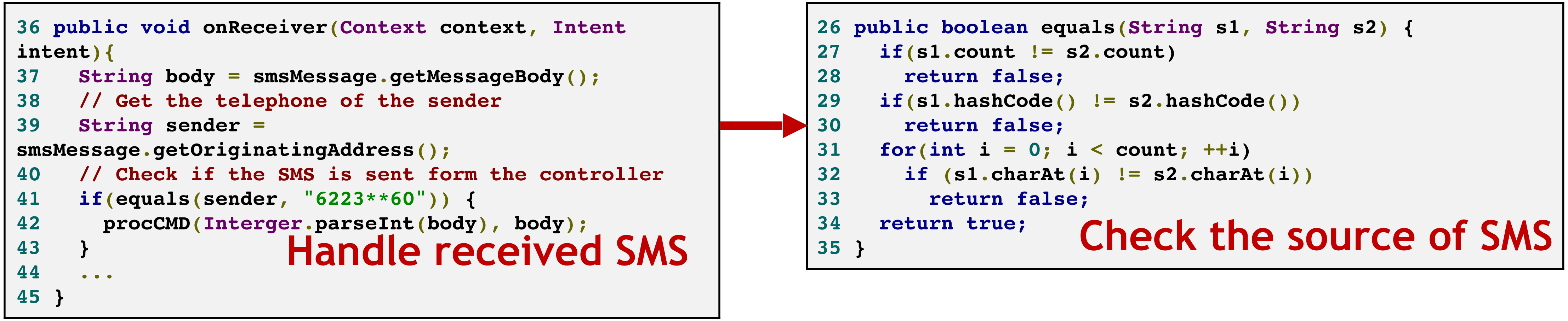
Motivating Example



```
public void onReceiver(Context context, Intent
intent){
  String body = smsMessage.getMessageBody();
  // Get the telephone of the sender
  String sender =
smsMessage.getOriginatingAddress();
  // Check if the SMS is sent form the controller
  if(equals(sender, "6223**60")) {
   procCMD(Interger.parseInt(body), body);
  }
  ...
}
```

Handle received SMS

Motivating Example



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Check the source of SMS

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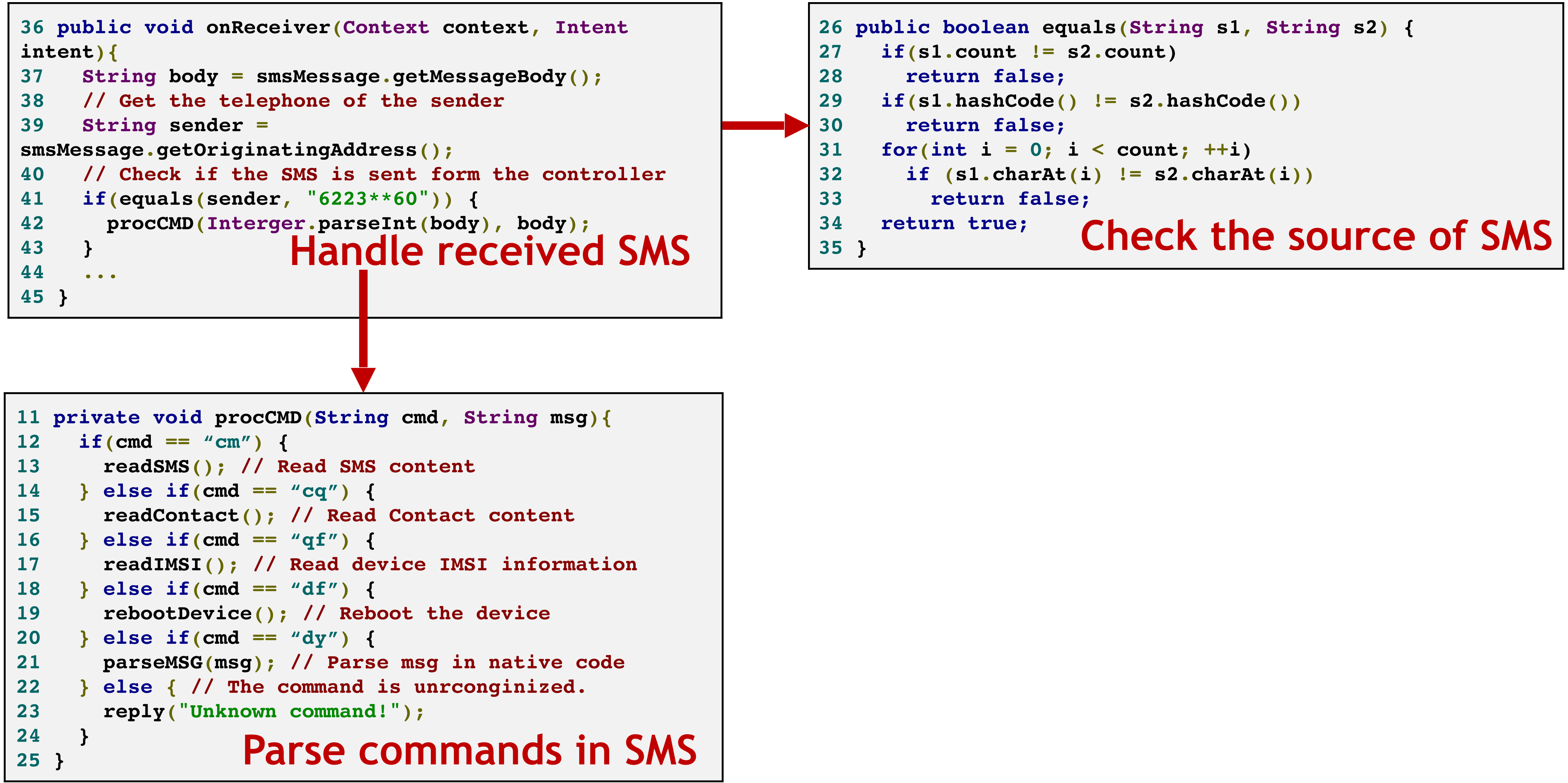

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    parseMSG(msg); // Parse msg in native code
  } else { // The command is unrconginized.
    reply("Unknown command!");
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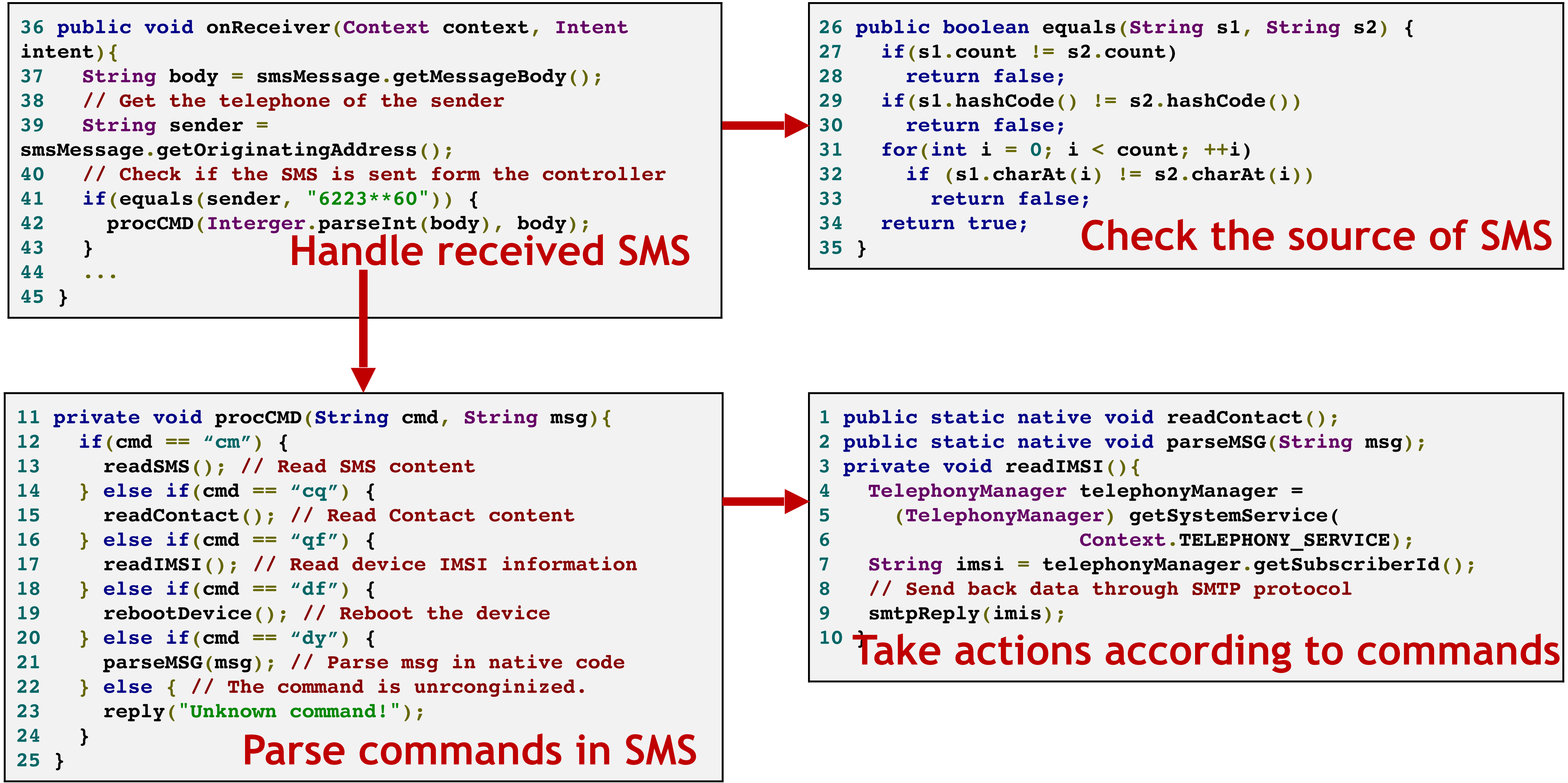
Parse commands in SMS



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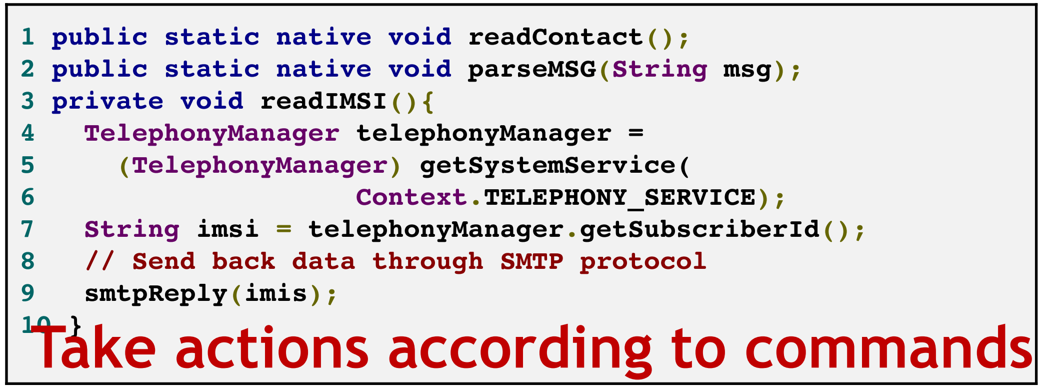
Take actions according to commands

Motivating Example

Challenges



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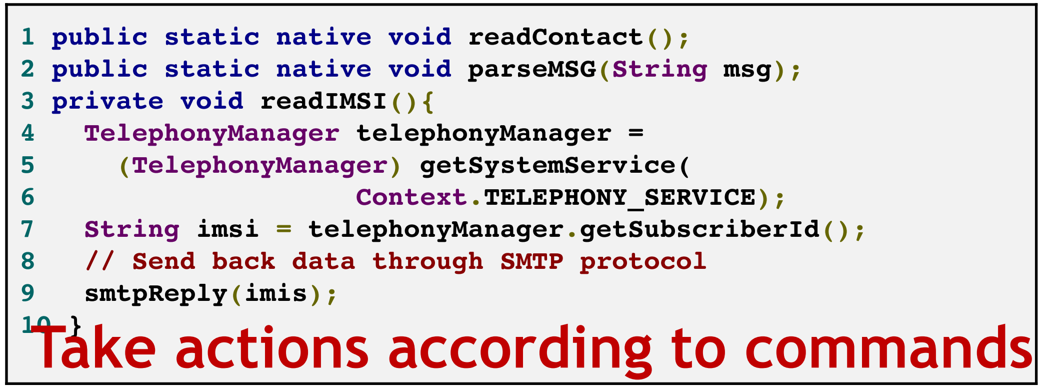

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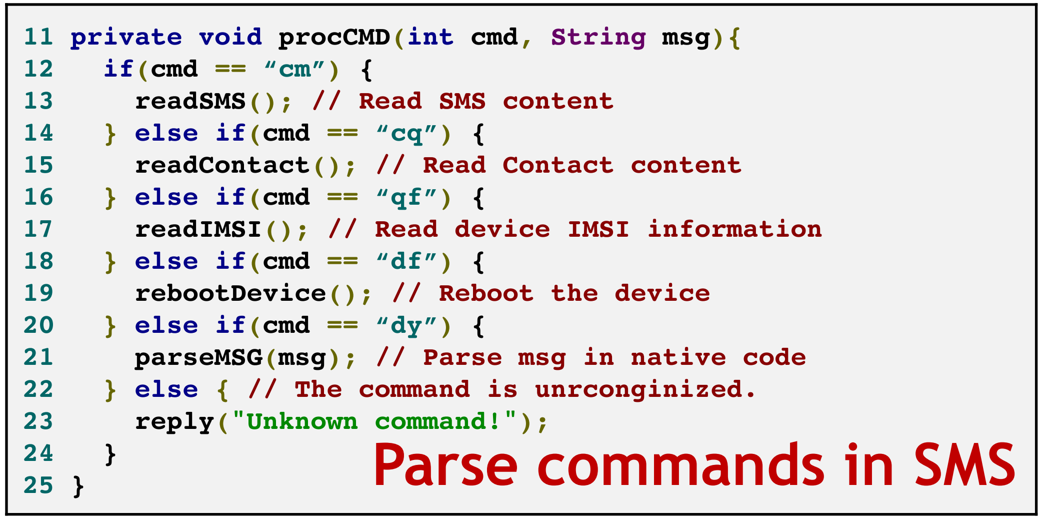
Identify the cross-layer information flow

Challenges



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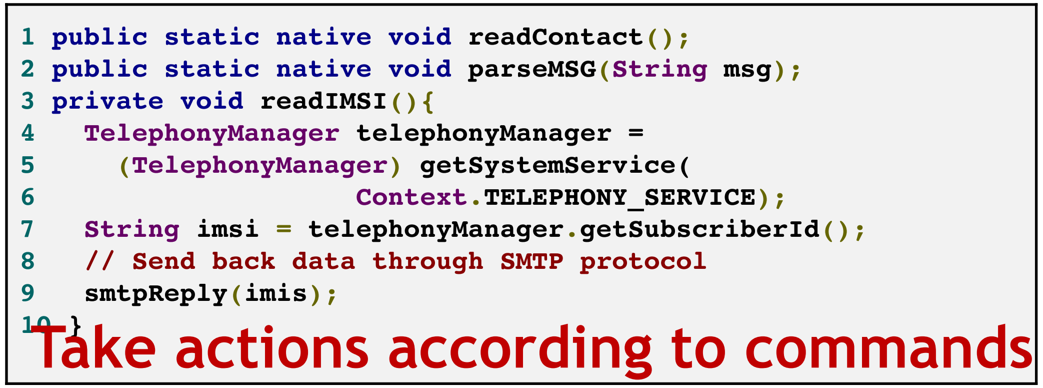

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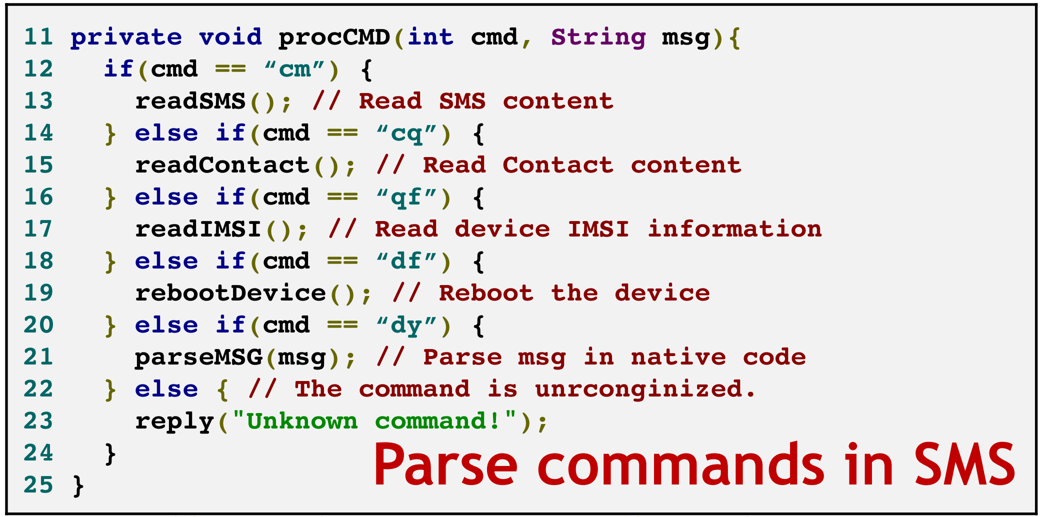

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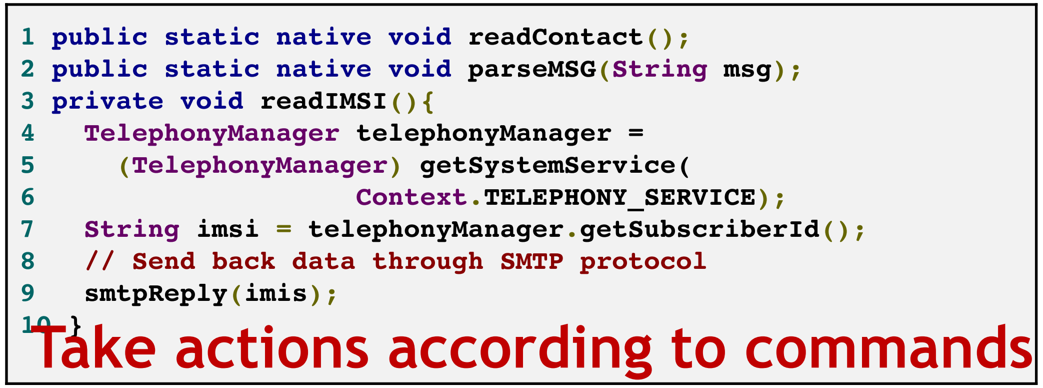
Parse commands in SMS

Expose all malicious payloads triggered by various commands efficiently



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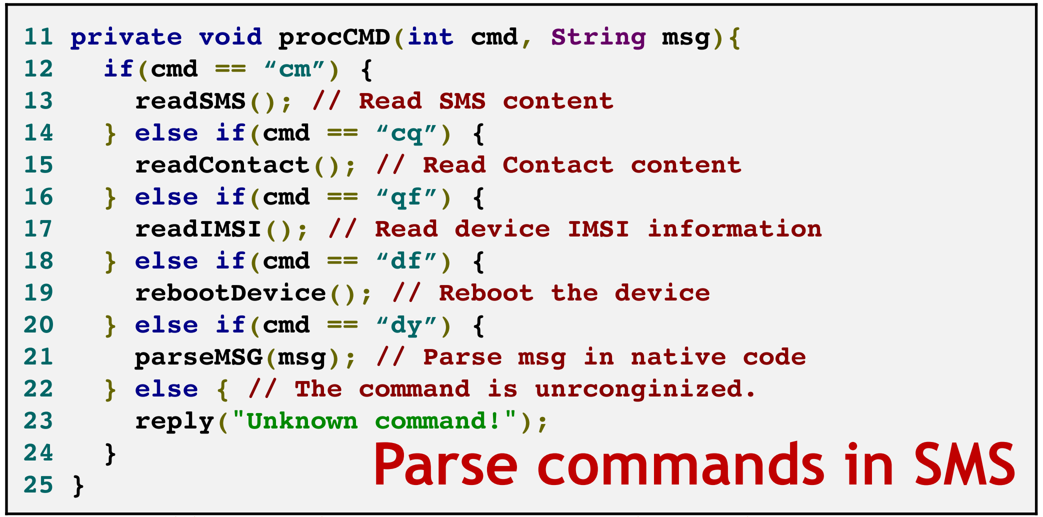

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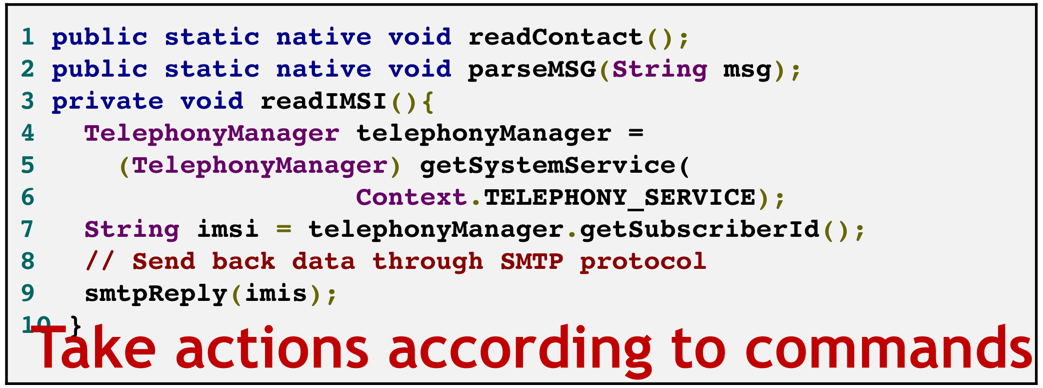

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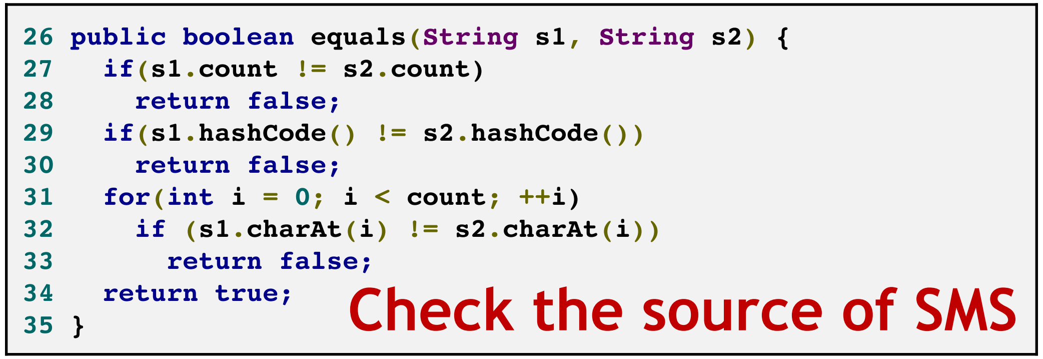

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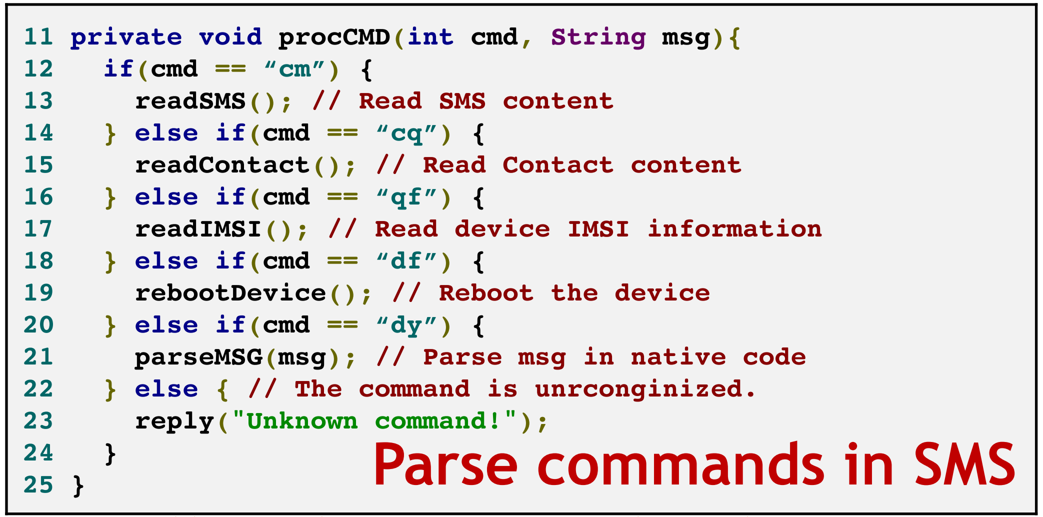
Challenges



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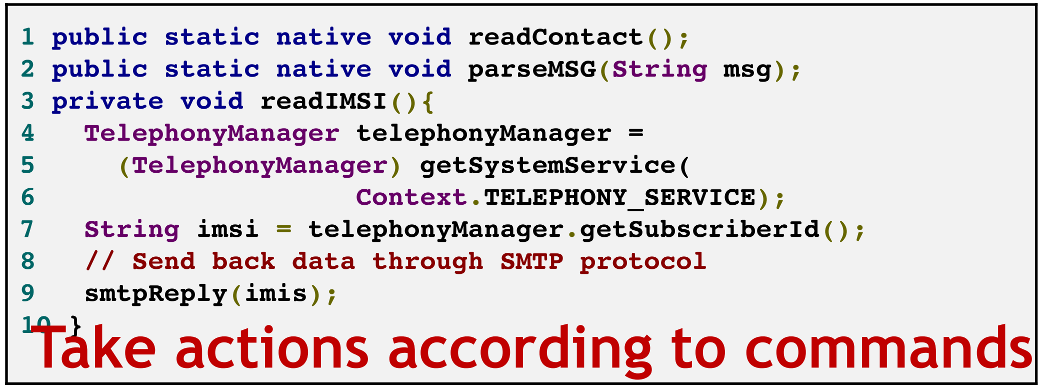

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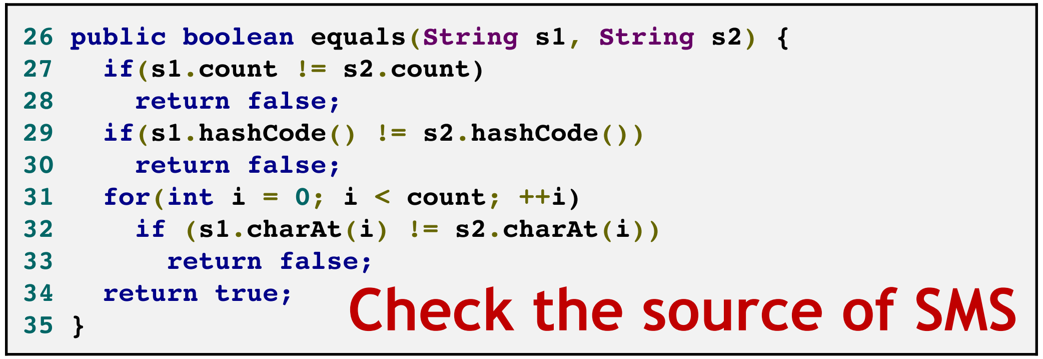

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Check the source of SMS

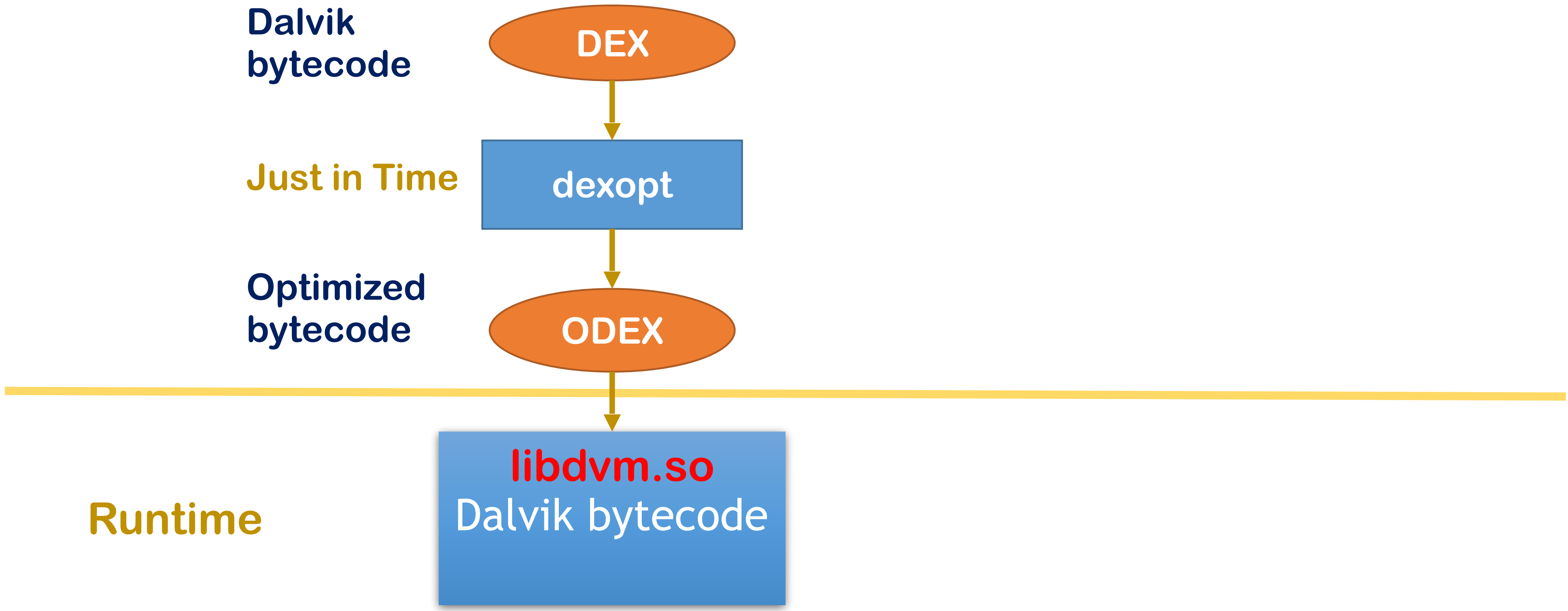
Force app to execute a certain path if the desired input cannot be generated.

Challenges

Agenda

- ❑ Motivating Example
- ❑ The New Android Runtime (ART)
- ❑ Malton
- ❑ Evaluation
- ❑ Conclusion

Android Runtime



Dalvik bytecode

DEX

Just in Time

dexopt

Optimized bytecode

ODEX

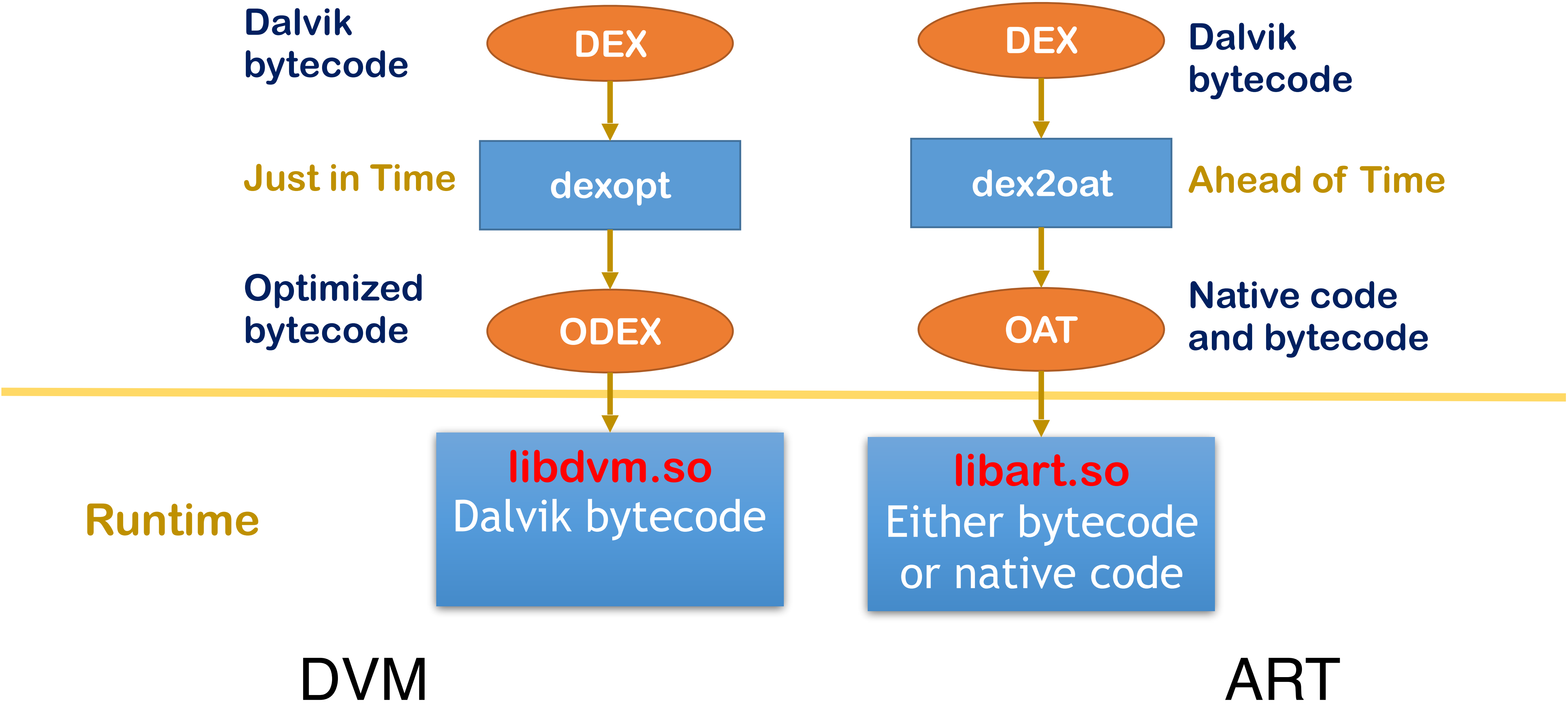
Runtime

libdvm.so

Dalvik bytecode

DVM

Android Runtime



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Runtime

libdvm.so
Dalvik bytecode

DVM

DEX

Dalvik bytecode

dex2oat

Ahead of Time

OAT

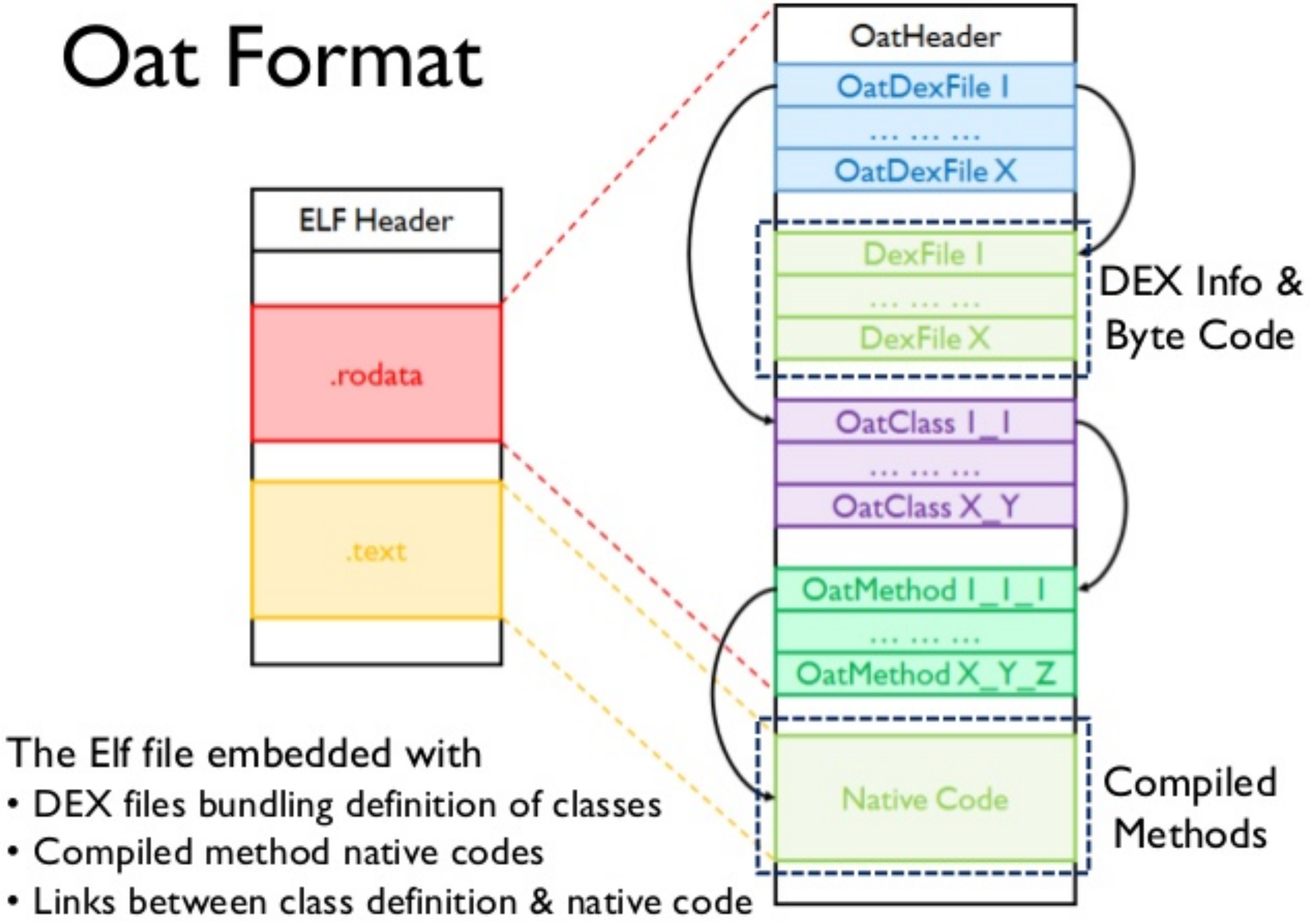
Native code and bytecode

libart.so
Either bytecode or native code

ART

Android Runtime

The OAT File



Oat Format

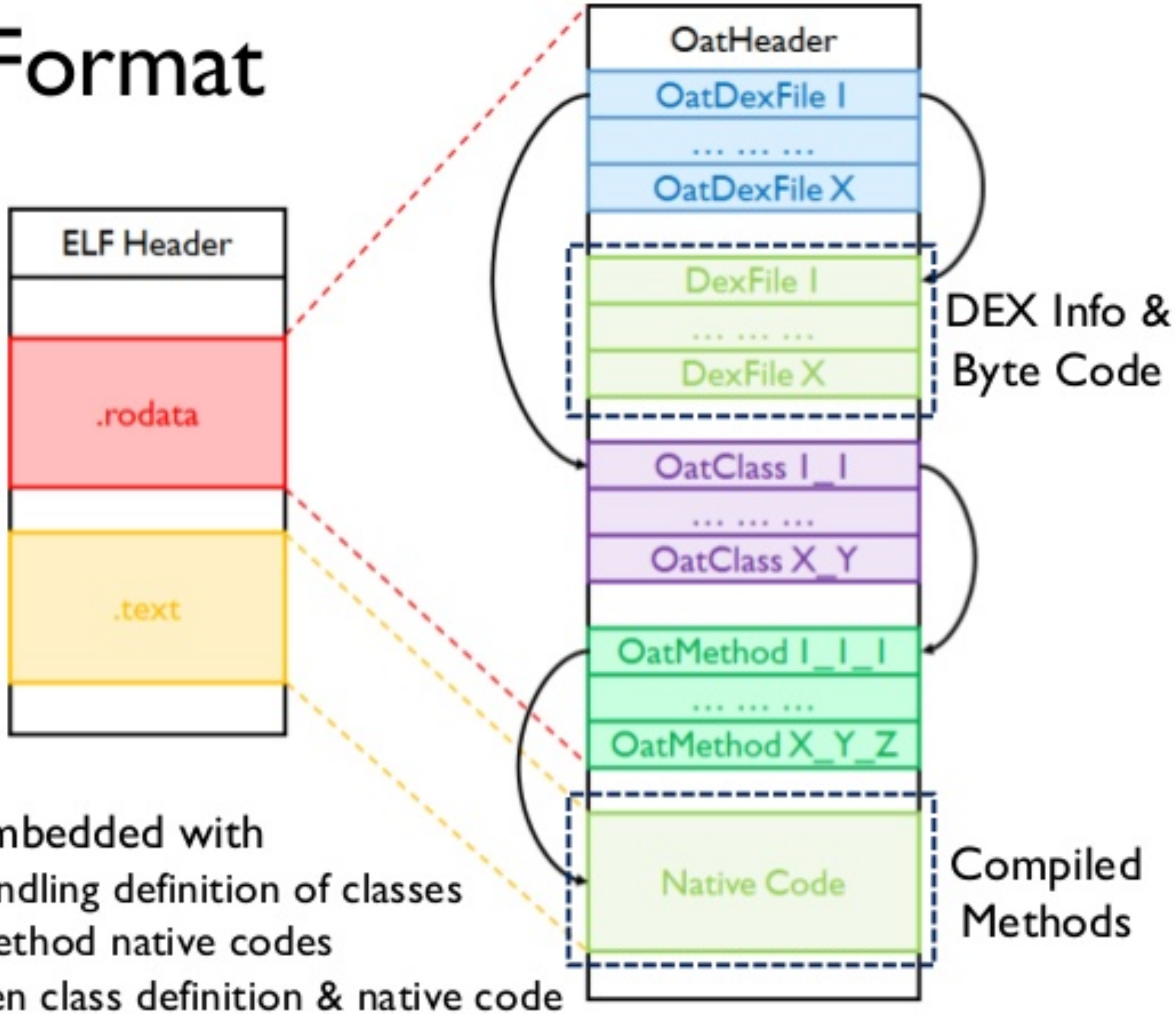
The Elf file embedded with

- DEX files bundling definition of classes
- Compiled method native codes
- Links between class definition & native code

The OAT File

Parse OAT files

Oat Format



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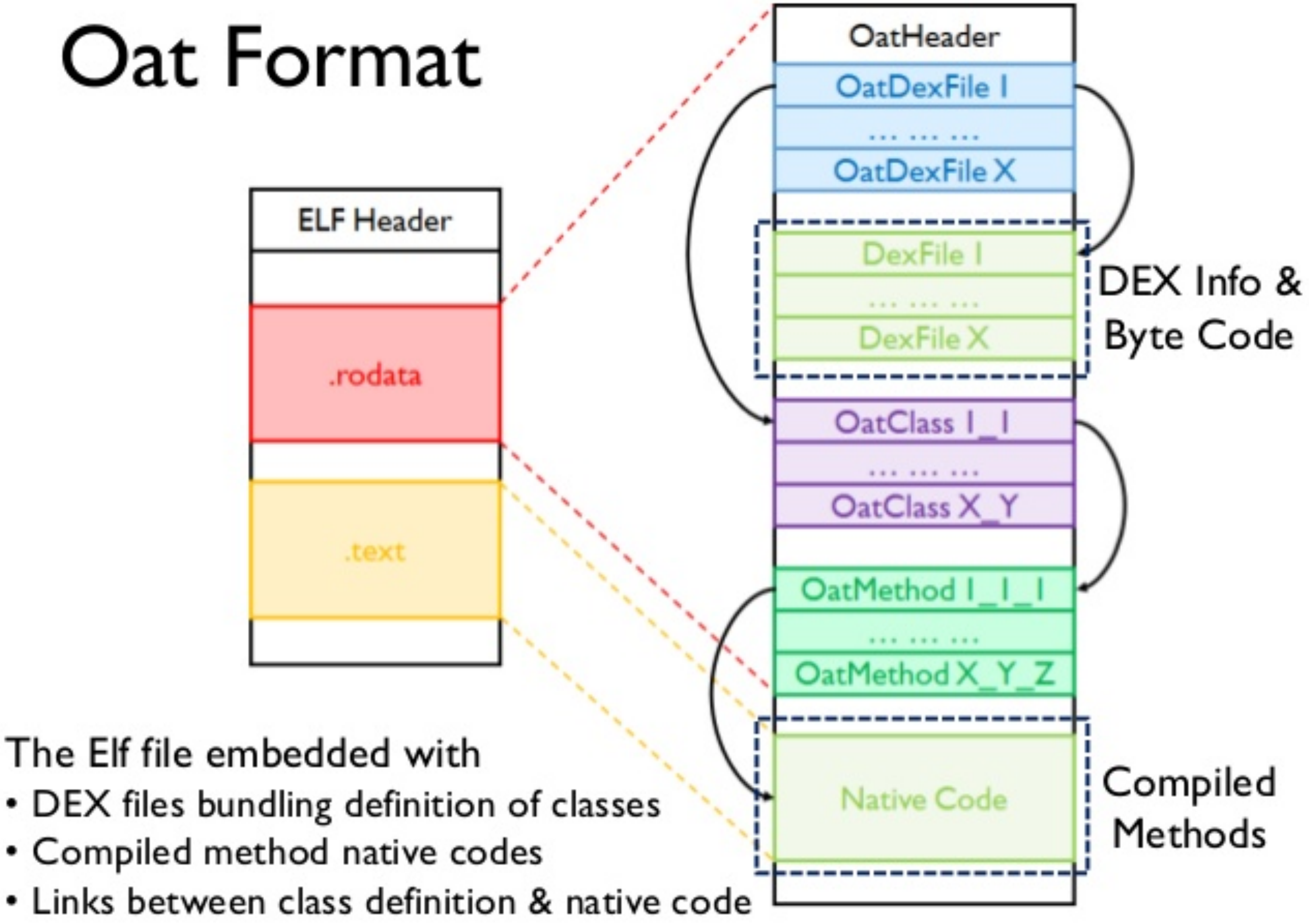

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Parse OAT files

↓

Get the code regions of compiled methods

The OAT File

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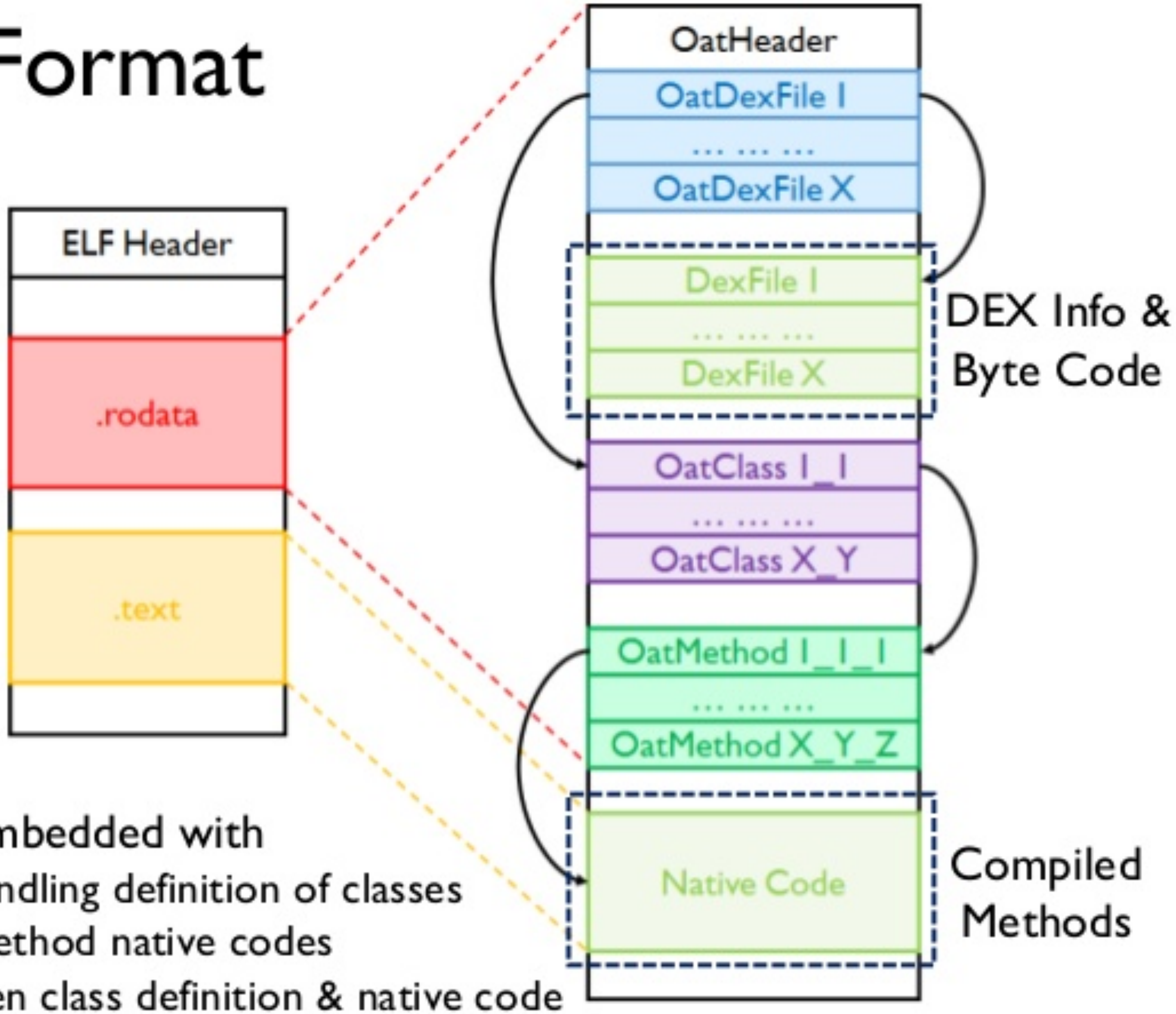

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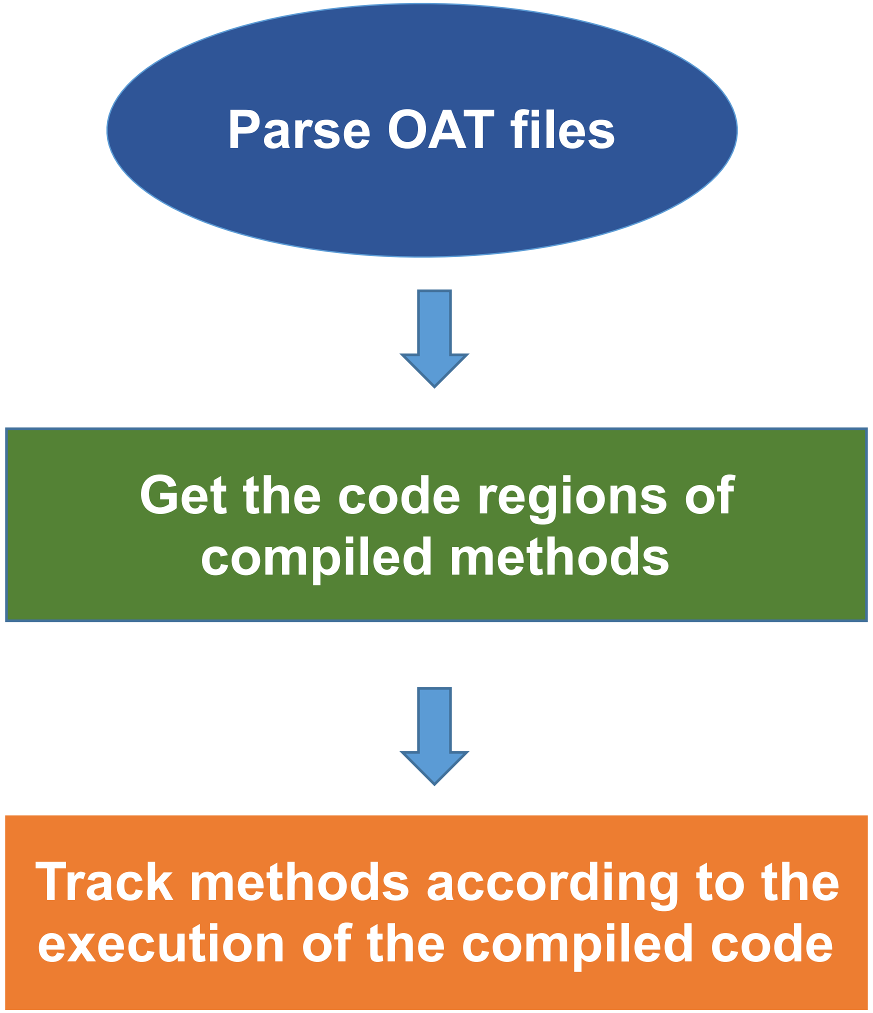

Parse OAT files

Get the code regions of compiled methods

Track methods according to the execution of the compiled code

Agenda

❑ Motivating Example

❑ The New Android Runtime (ART)

❑ **Malton**

❑ Evaluation

❑ Conclusion

APK
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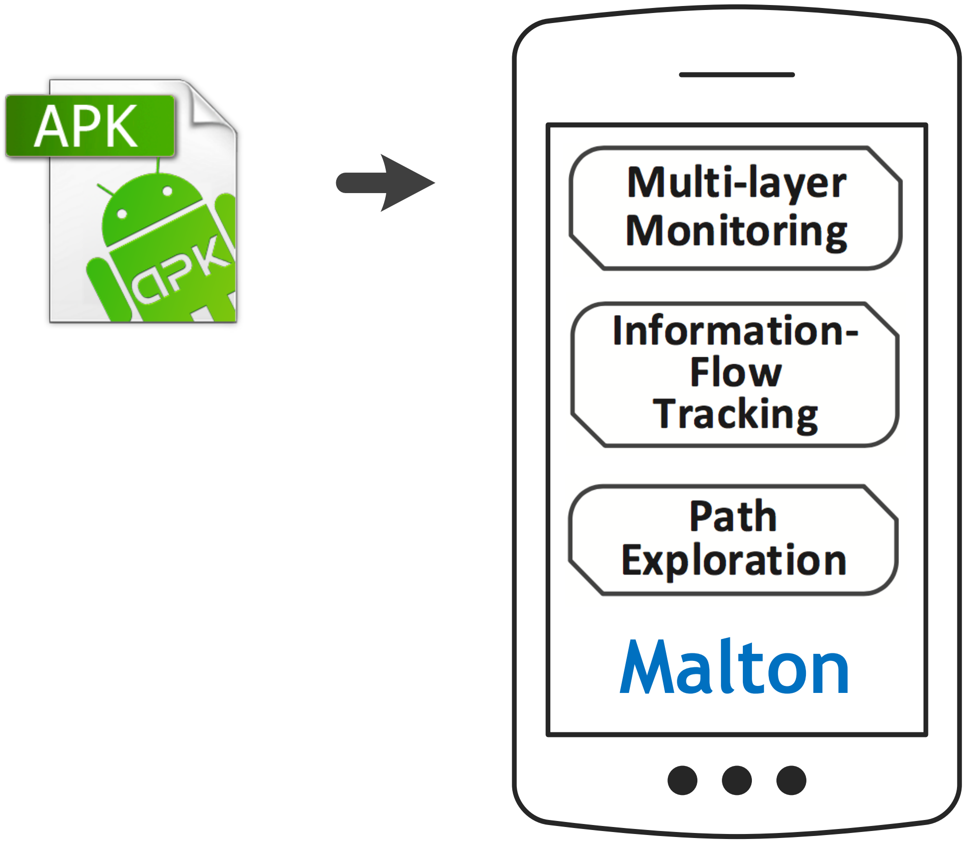
- **Running on a real device;**
- **Conducting cross-layer monitoring and information flow tracking;**
- **Doesn’t need to modify the app.**



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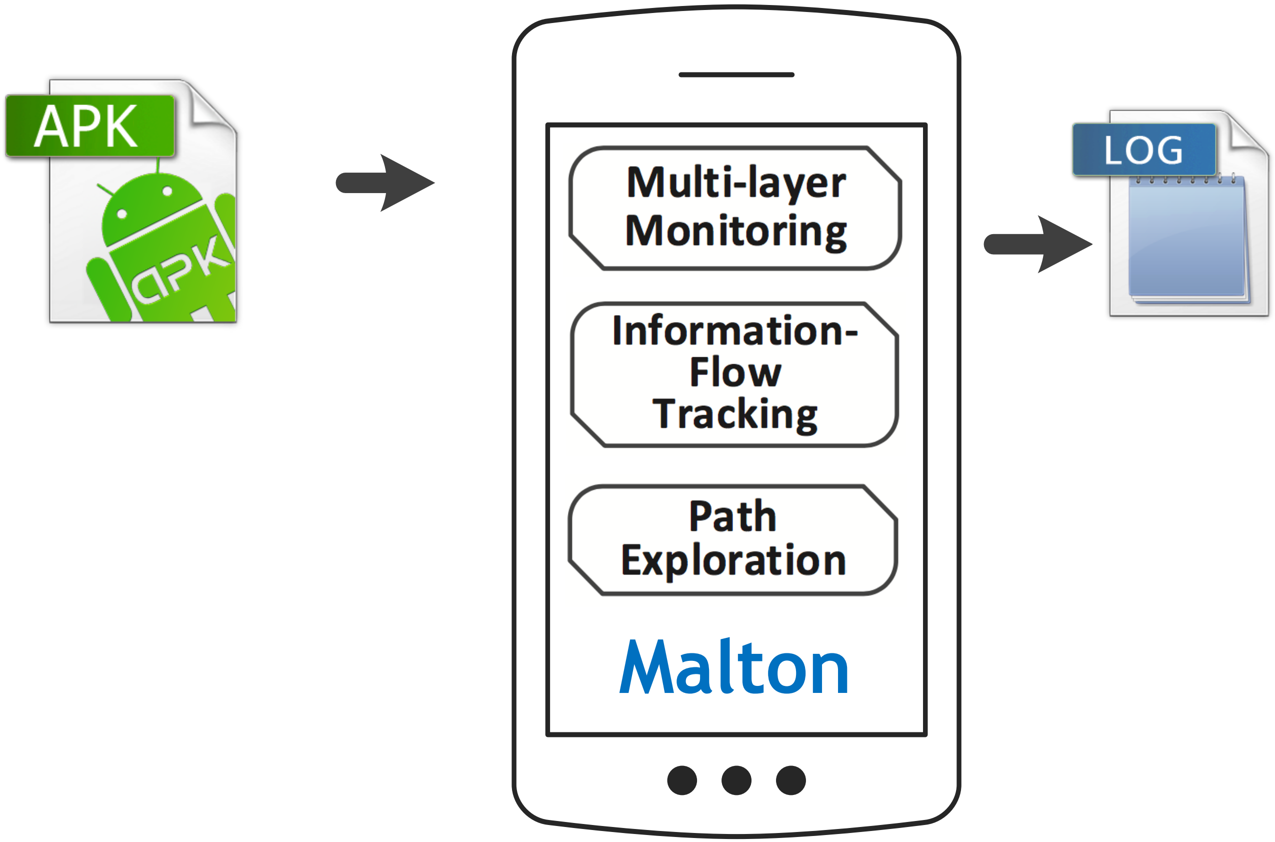

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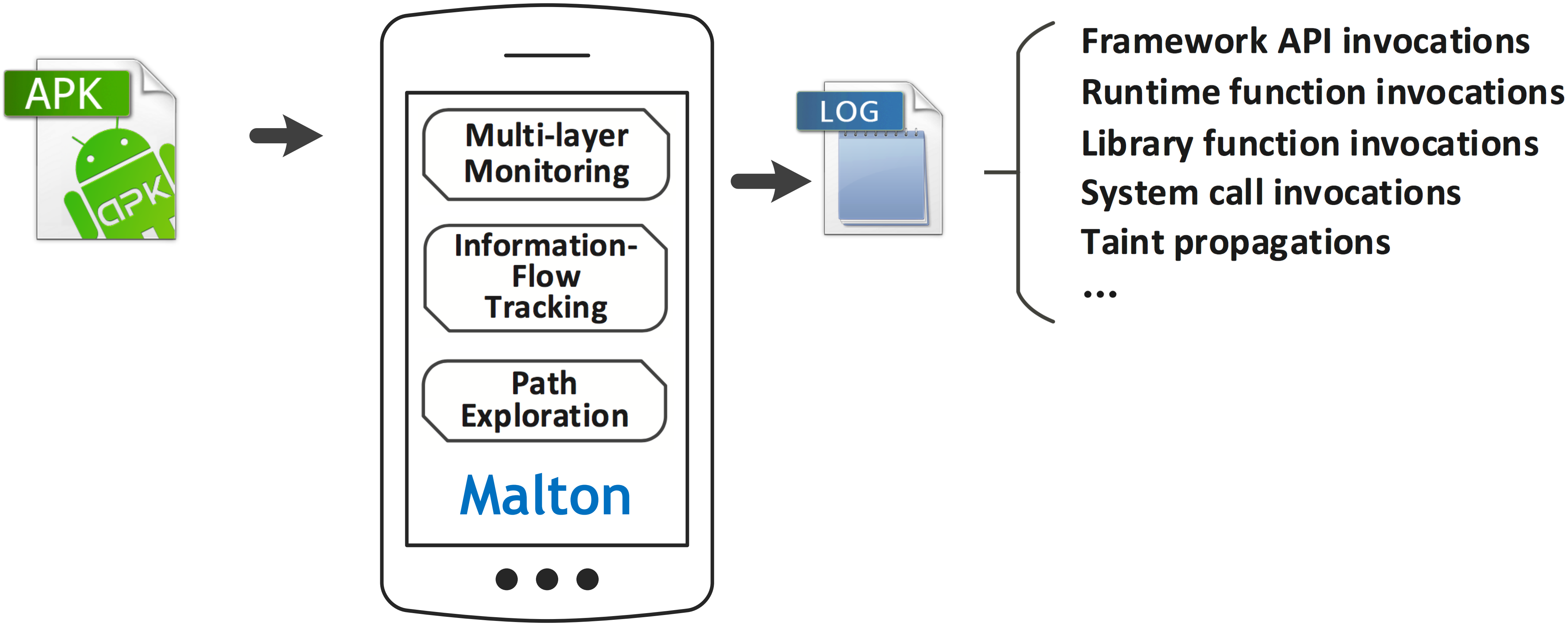
APK
Multi-layer Monitoring
Information-Flow Tracking
Path Exploration
Malton
LOG
Framework API invocations
Runtime function invocations
Library function invocations
System call invocations
Taint propagations
…

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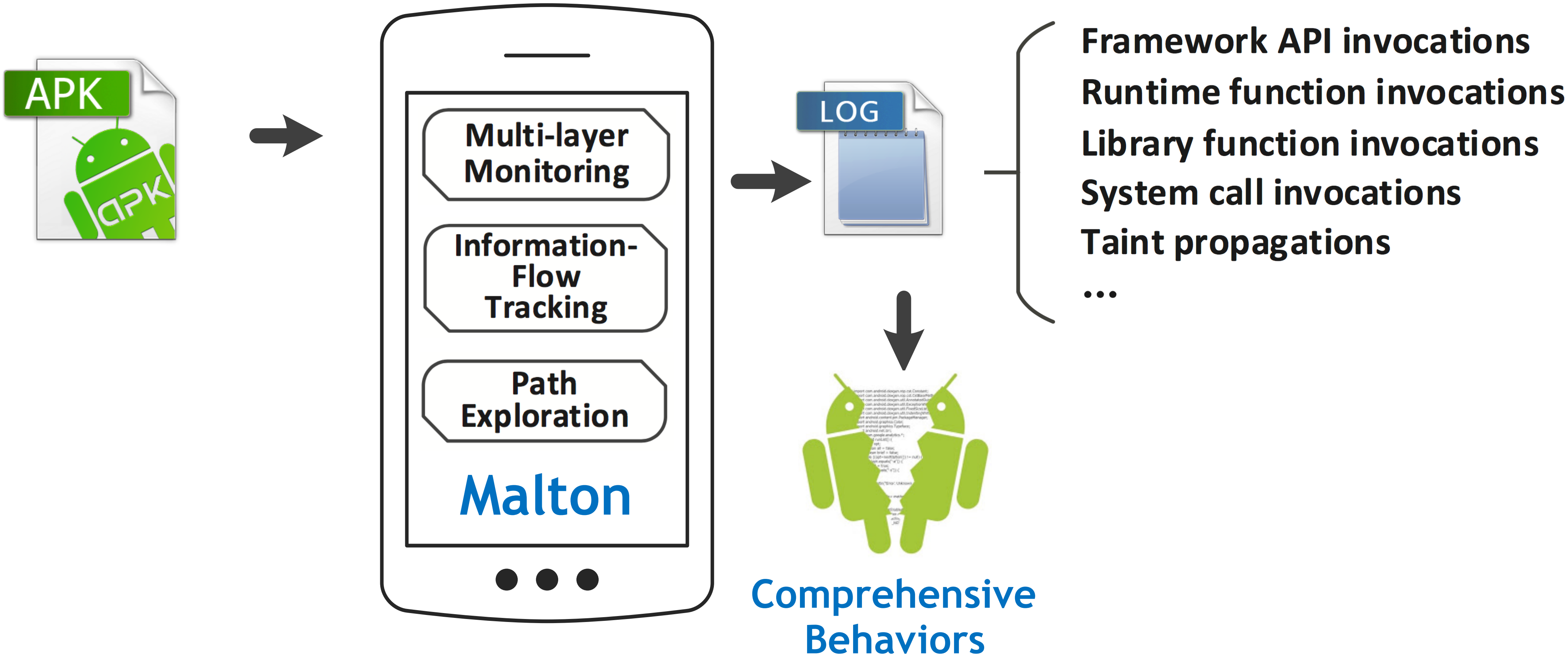

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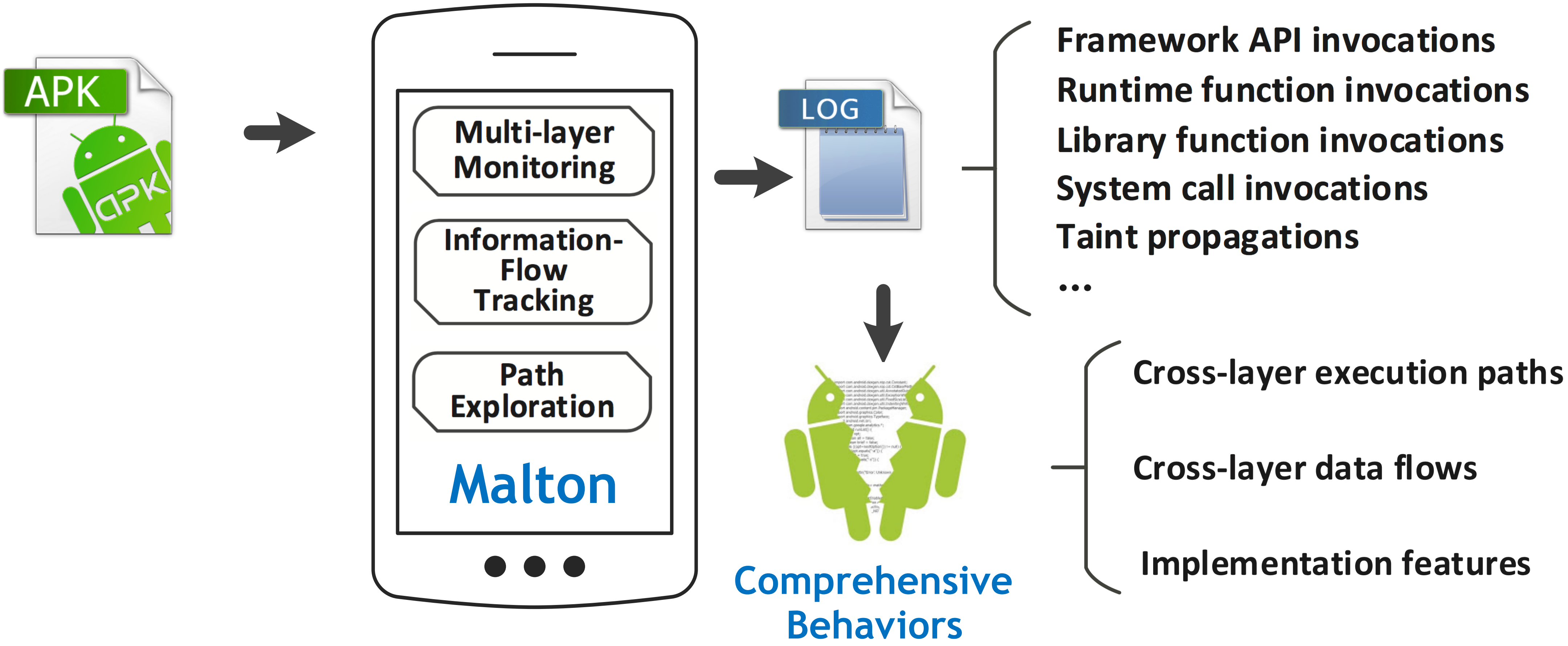

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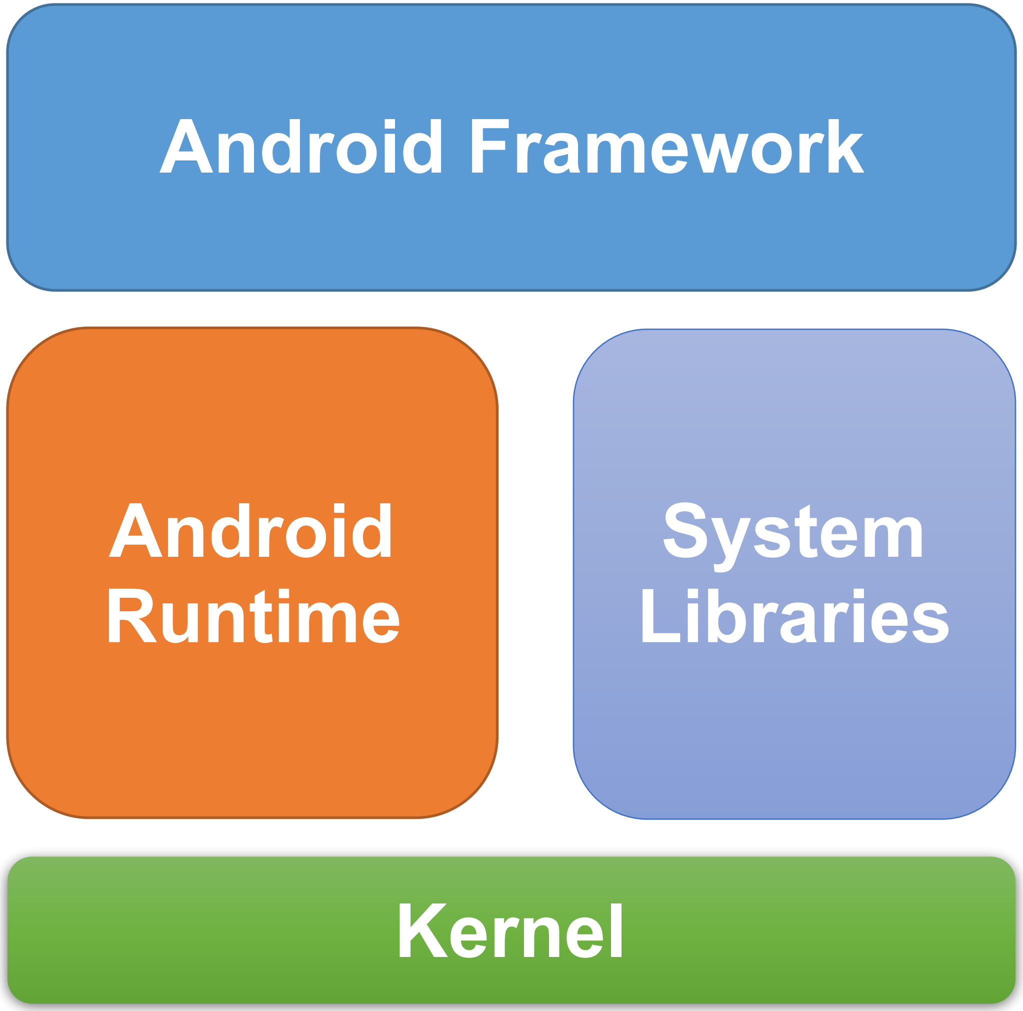
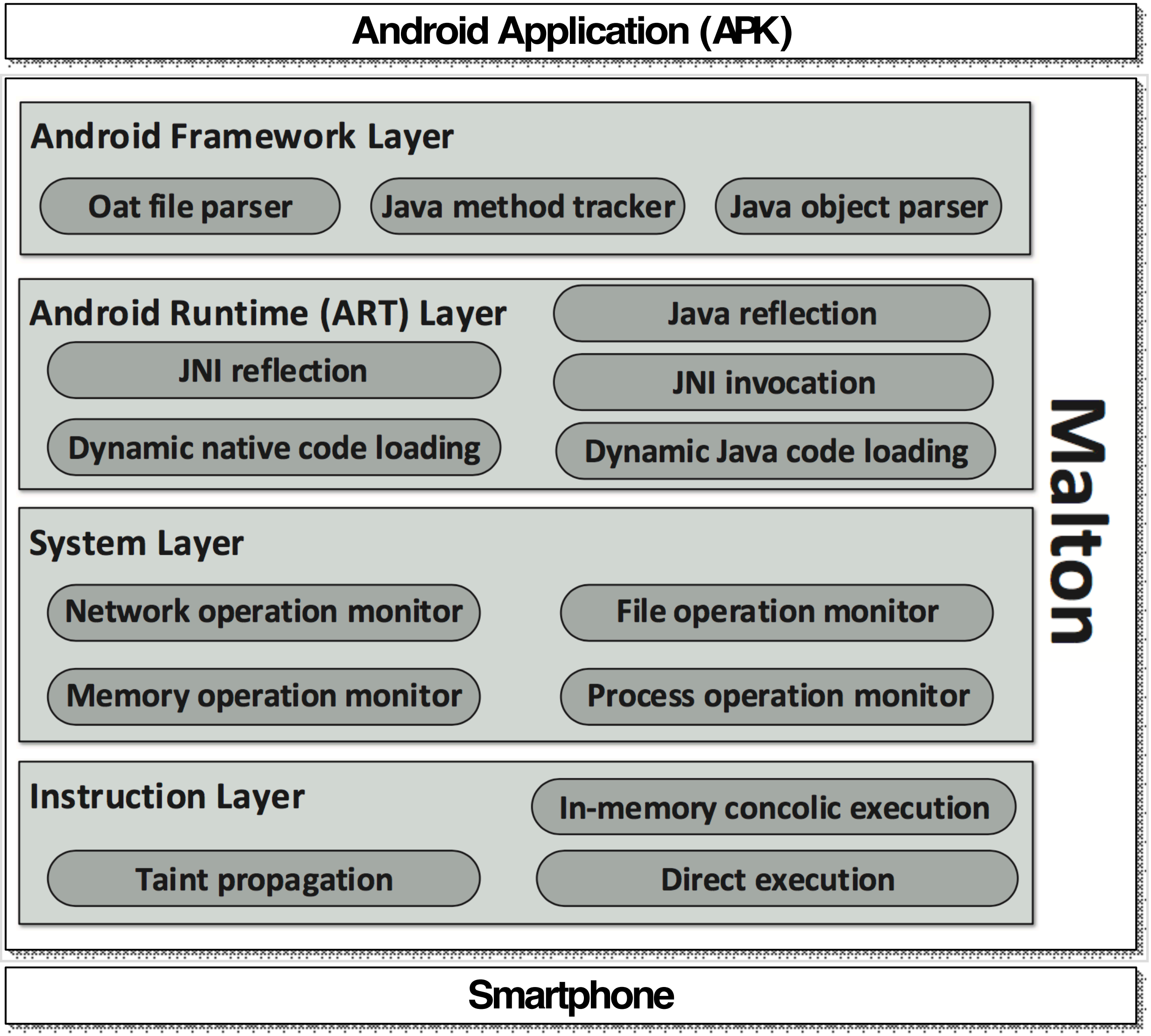
The Design of Malton





Android Framework Layer

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❑ OAT File Parser

- Get the beginning addresses of the compiled methods.
- Get the types of the methods’ parameters and return values.

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Malton can be easily extended to support the tracking of new behaviors.

System Layer

System Layer

Android NDK

❑ **Network Operations**

- Monitor information leaked through network.
- Monitor the received remote commands.

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- ❑ **Process Operations**
  - Monitor protection behaviors (e.g., anti-emulator and anti-debugging)

Instruction Layer

Instruction Layer

- **Taint Propagation**
  - Track the information leakage flow.

Instruction Layer

❑ **Taint Propagation**

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❑ **In-memory Concolic Execution**

- Explore more execution paths.

Instruction Layer

- **Taint Propagation**
  - Track the information leakage flow.
- **In-memory Concolic Execution**
  - Explore more execution paths.
- **Direct Execution**
  - Explore execution path, of which no input is generated.

Taint Propagation

We propagate taint tags according to the logics of 9 IR statements and 11 IR expressions.

```
……
t12 = Load(0xabcd1234)
Put(8) = t12
……
```

Execution

Taint Propagation

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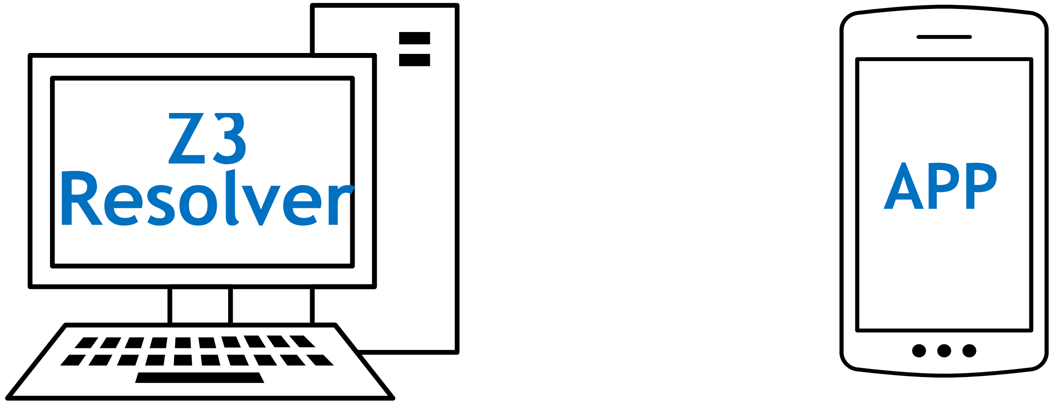
```

Execution

```
……
Taint(t12) = Taint(0xabcd1234)
Taint(8) = Taint(t12)
……
```

Taint propagations

Path Exploration

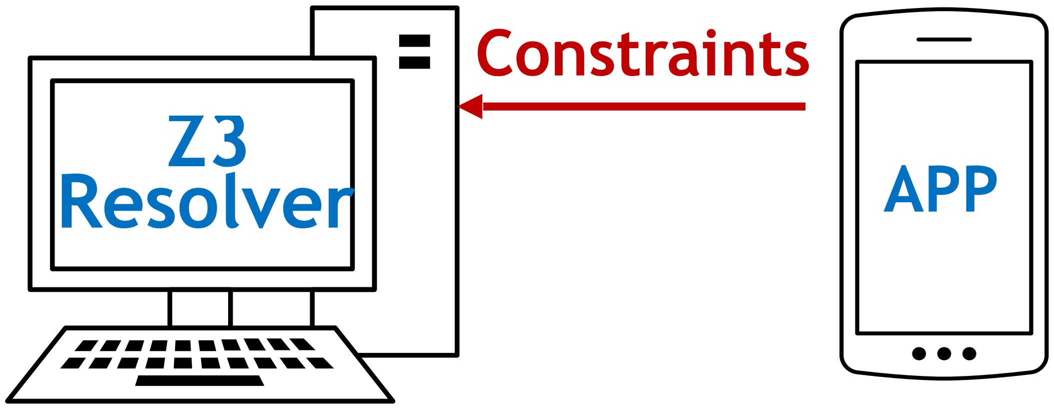


Desktop

Phone

Concolic Execution with Offloading Mechanism

Path Exploration



Z3 Resolver

Constraints

APP

Desktop

Phone

Concolic Execution with Offloading Mechanism

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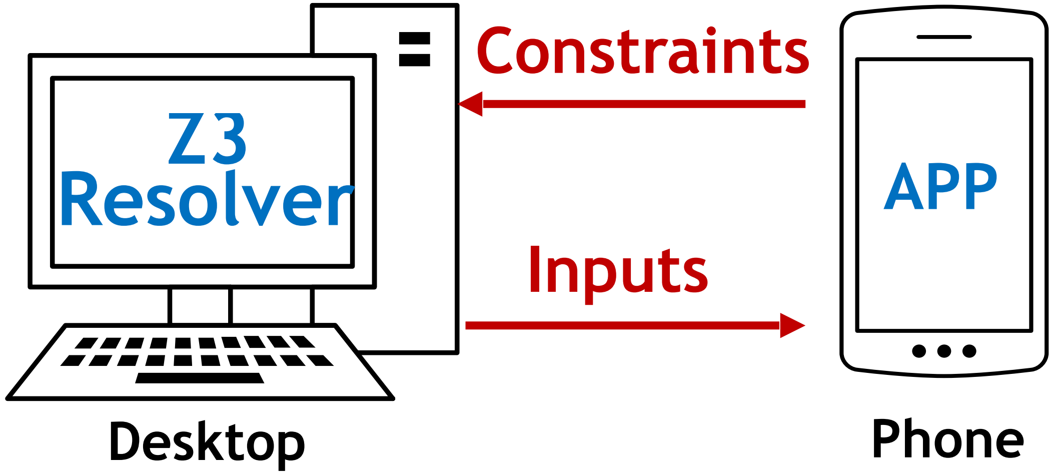

Concolic Execution with Offloading Mechanism

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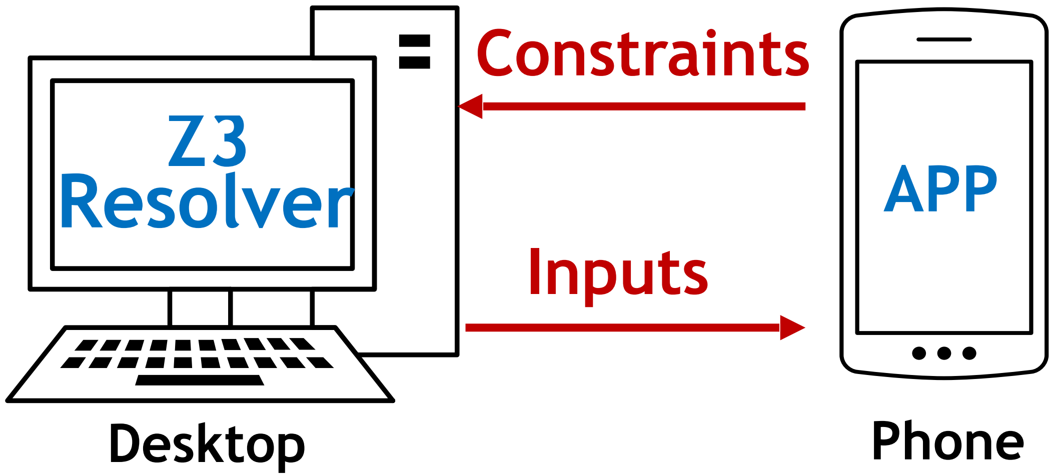

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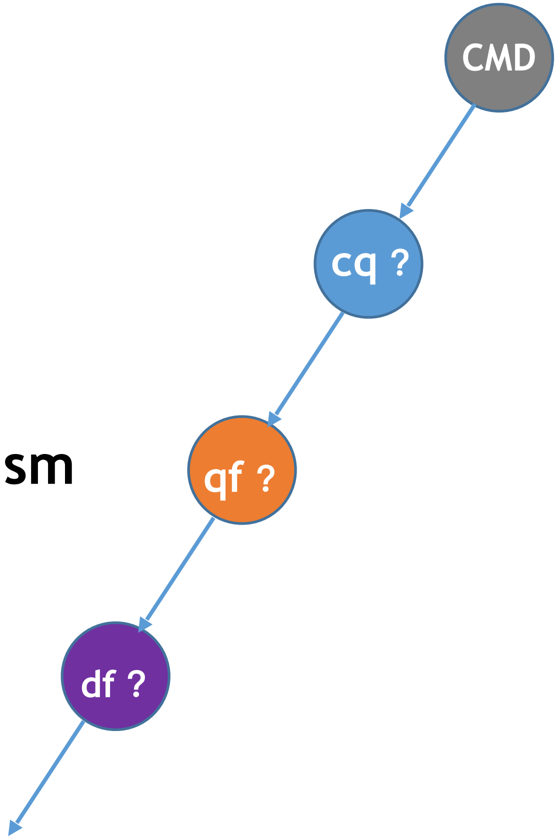

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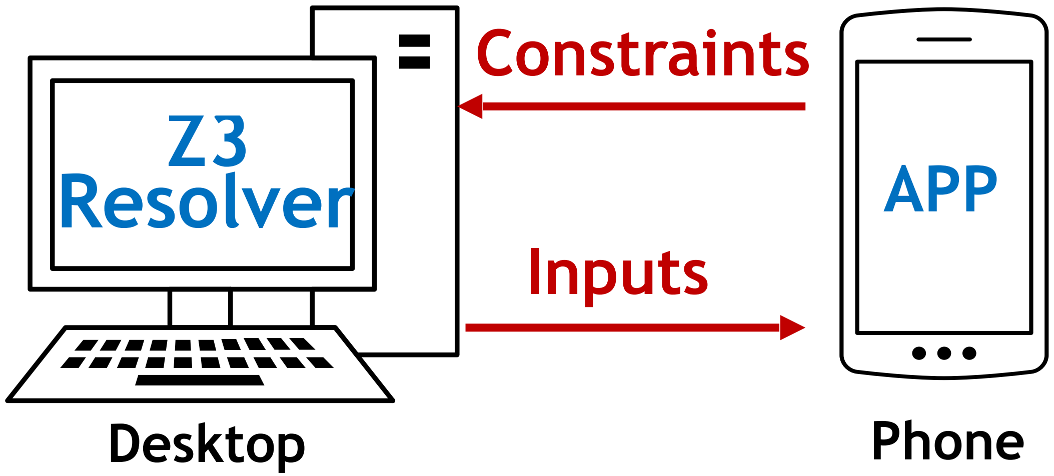

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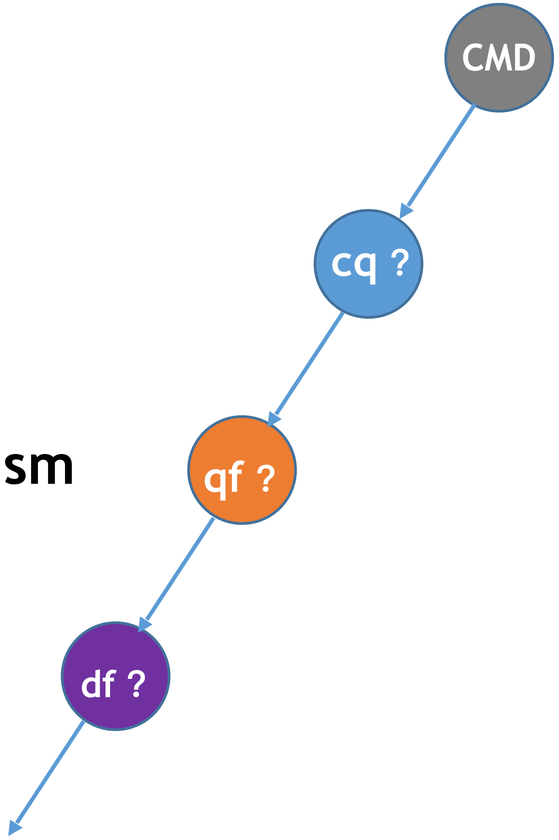

Constraints:

```
 CMD == “cq” ?
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 CMD == ”df” ?
 …
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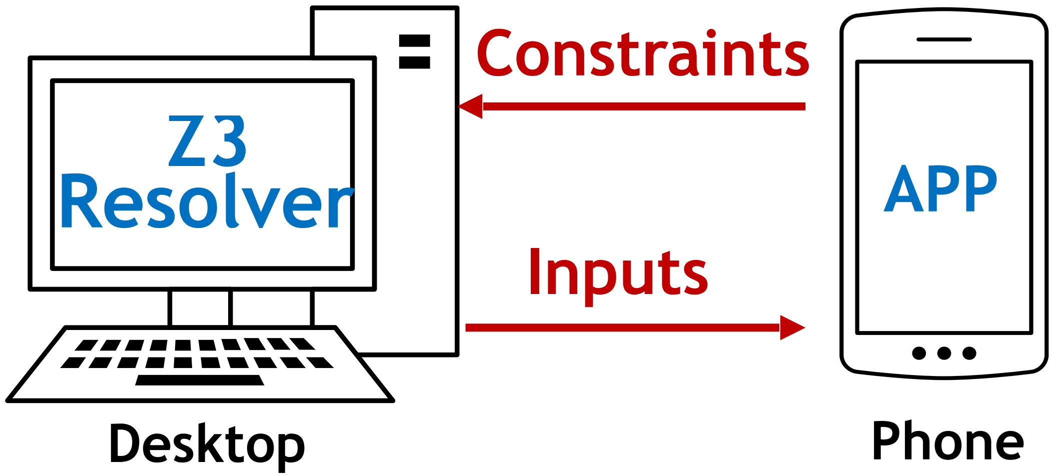
Path Exploration



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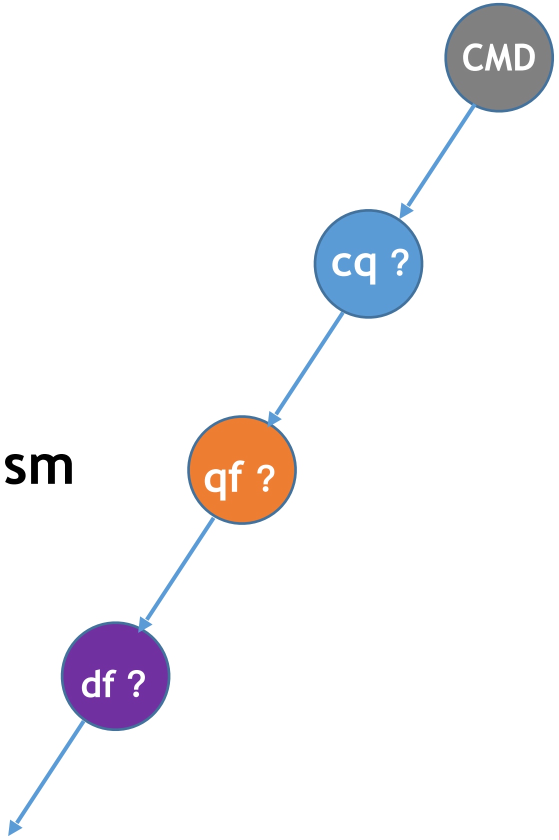

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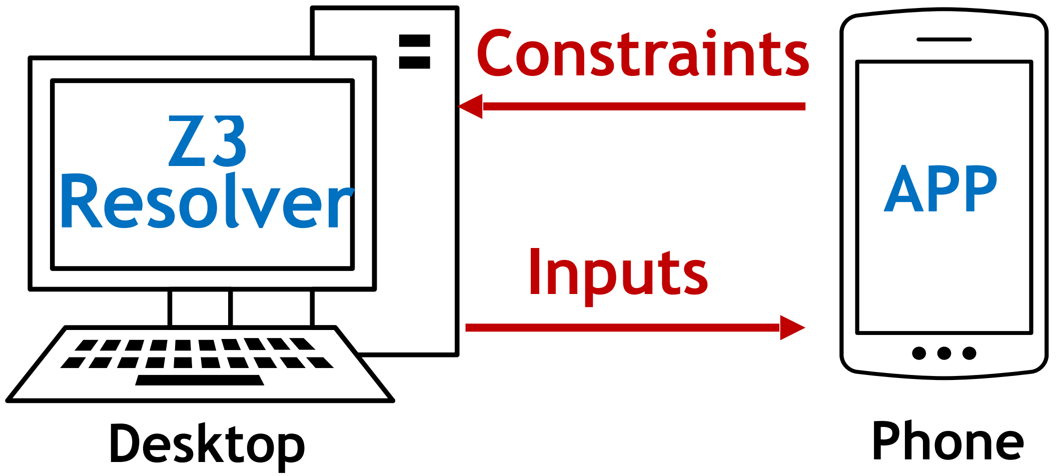

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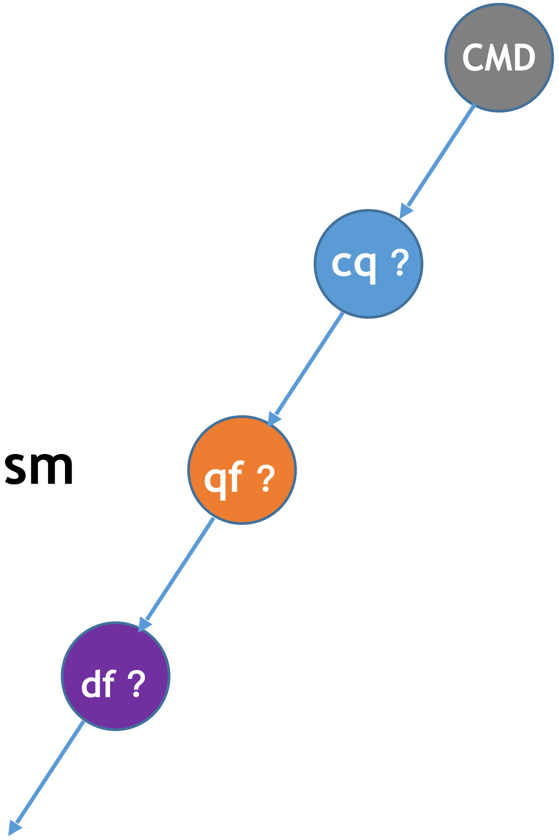

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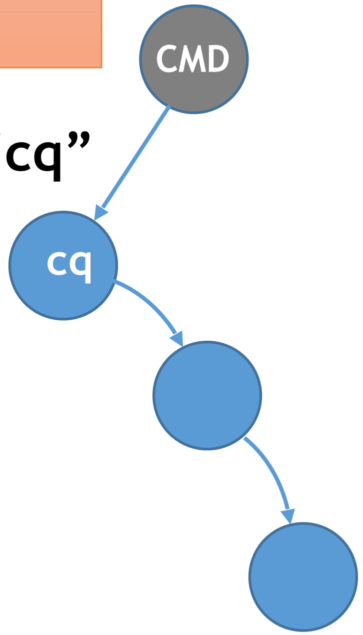
CMD = “cq”



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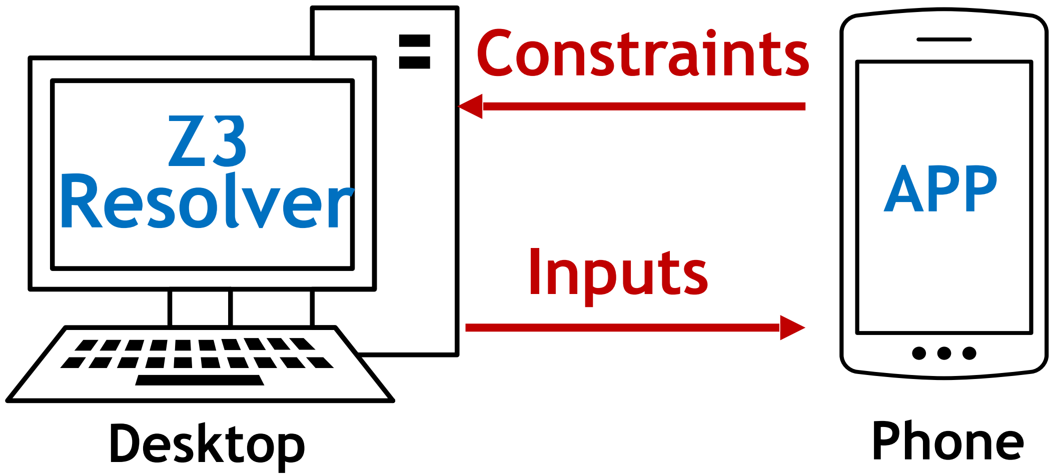

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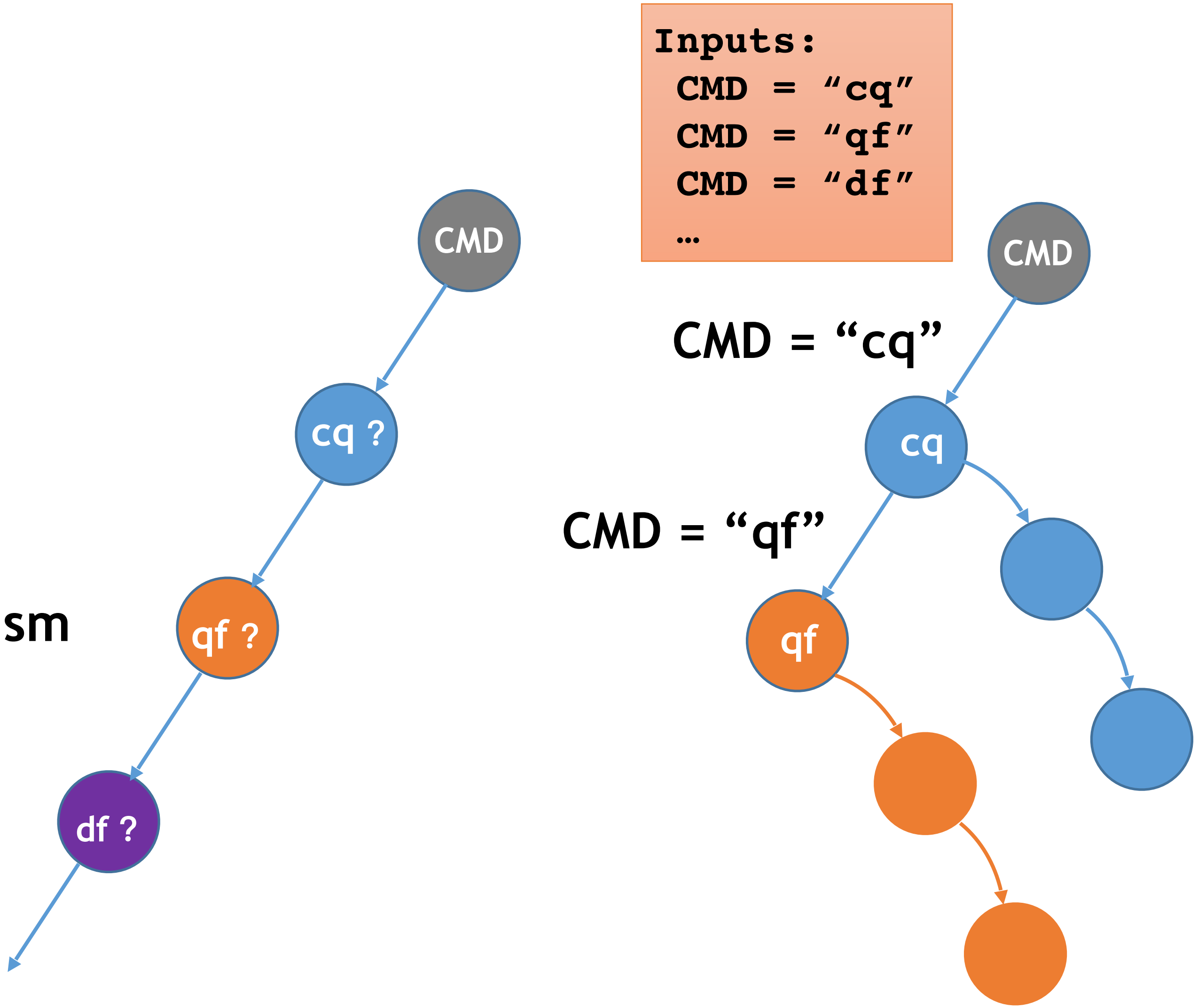

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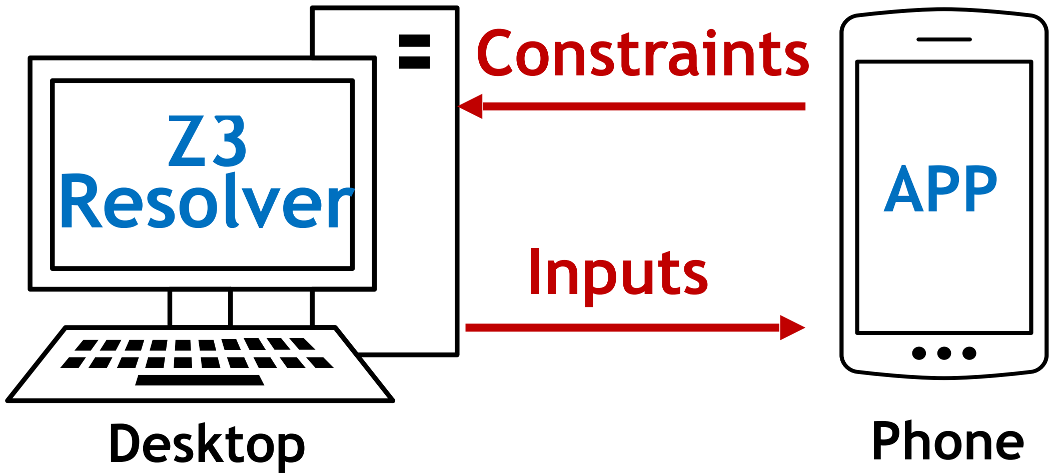

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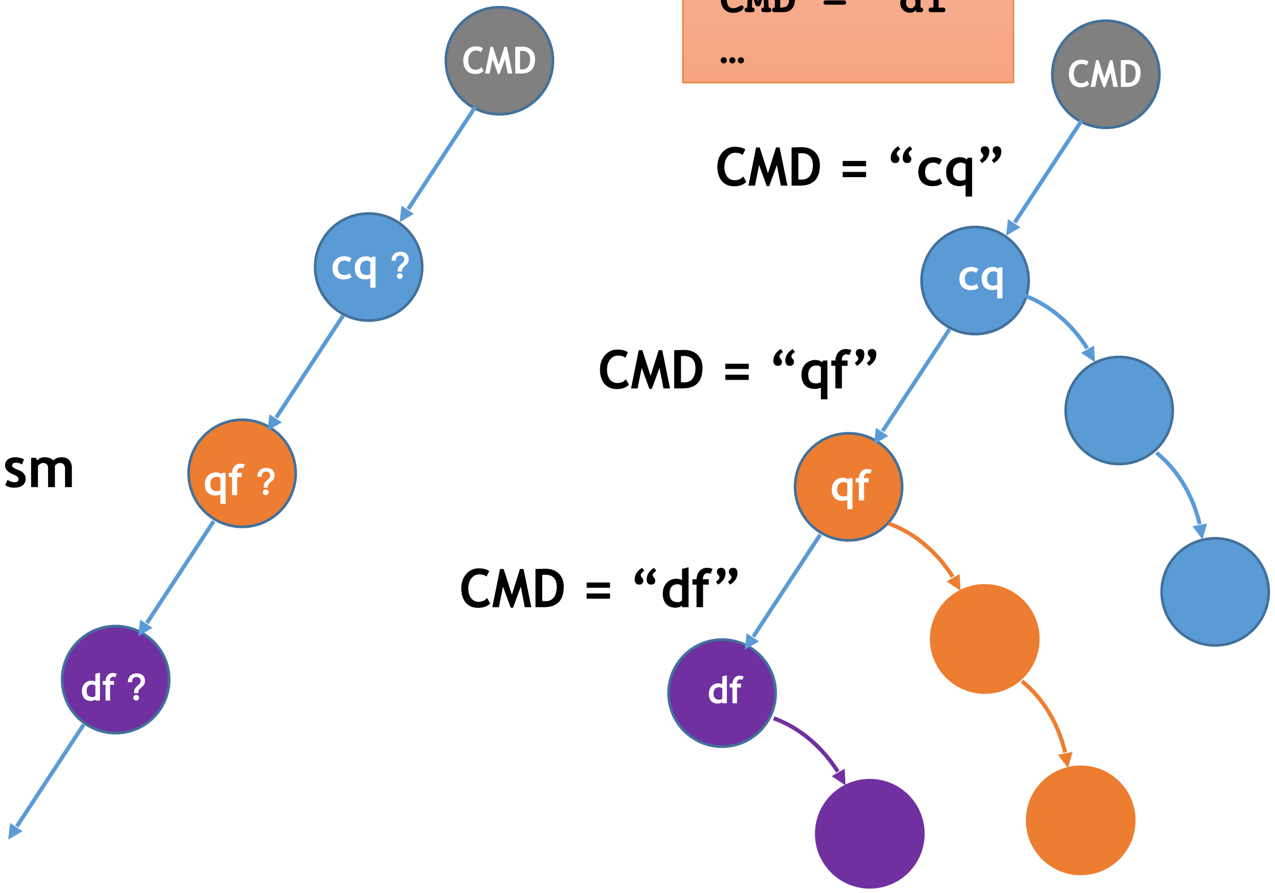

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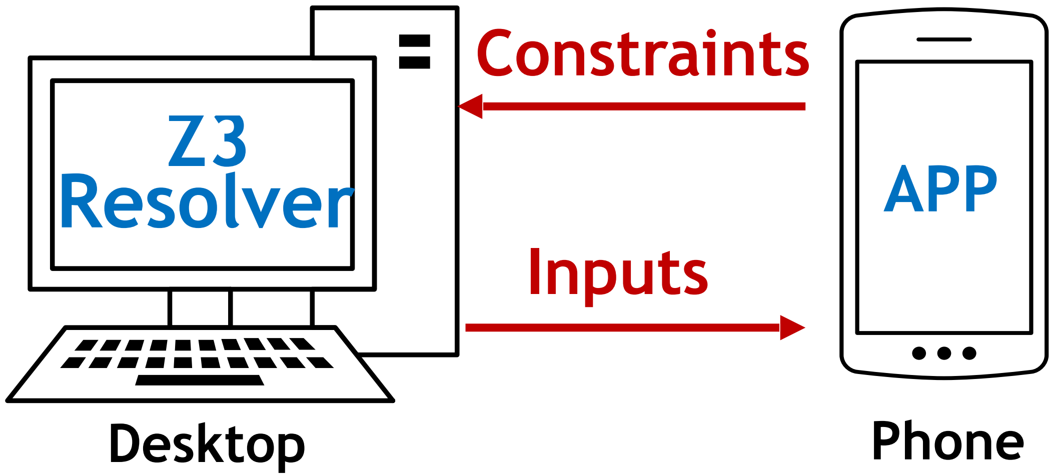

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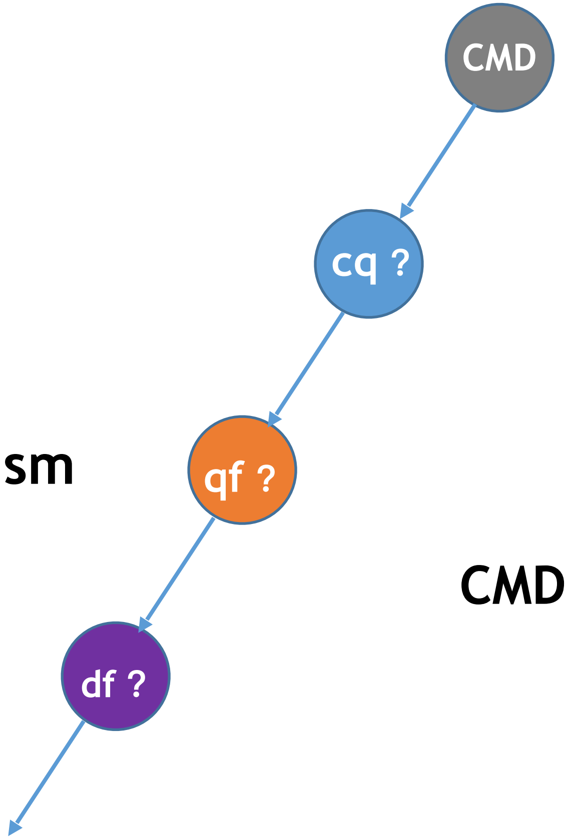

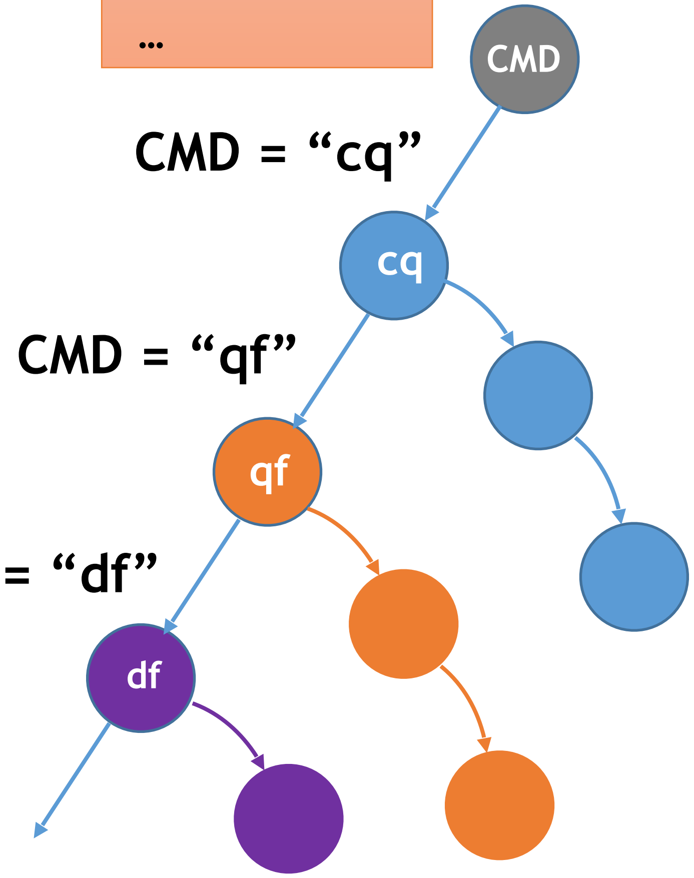

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In-memory optimization：

Run specified code regions iteratively with different inputs

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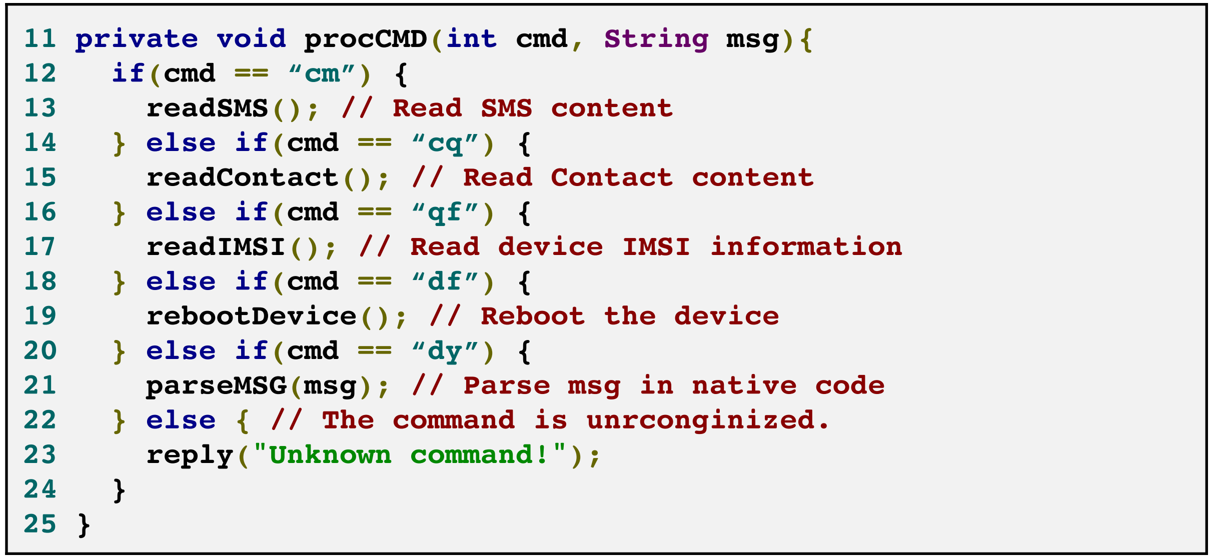

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private void procCMD(int cmd, String msg){
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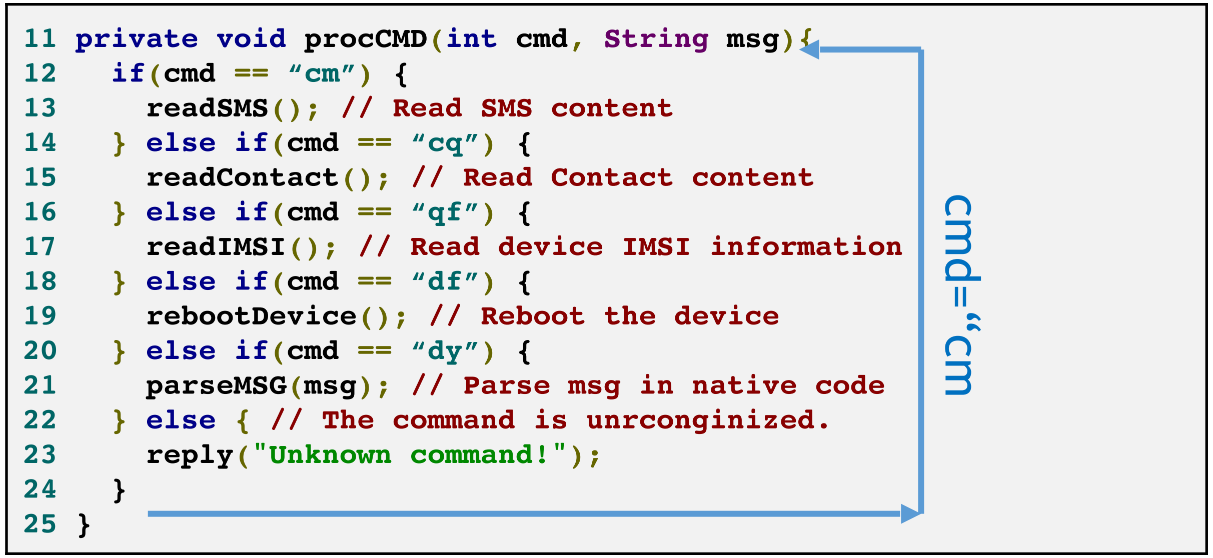

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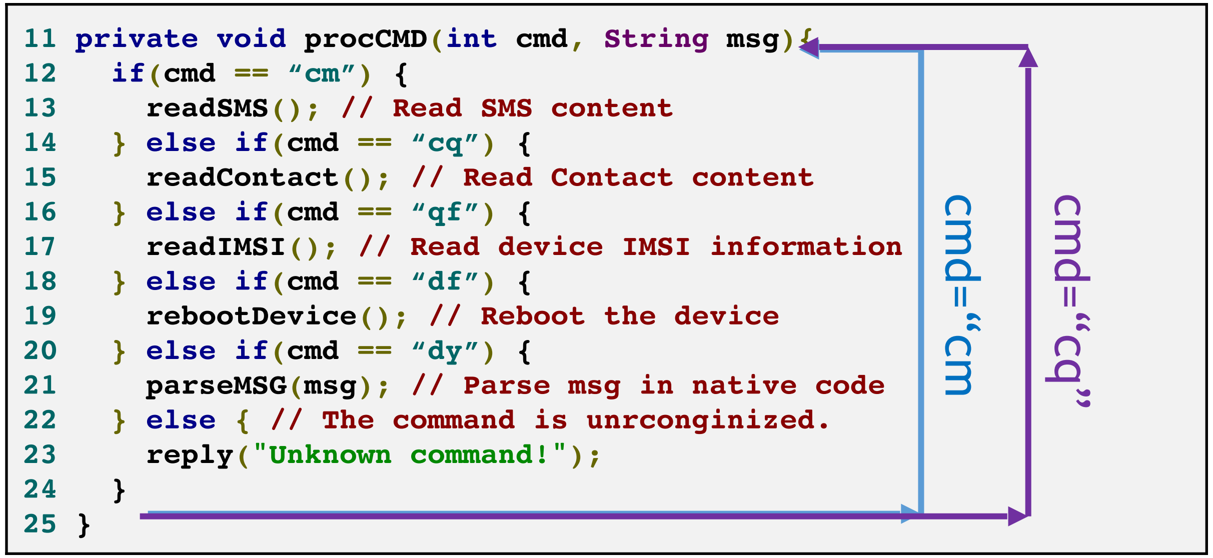

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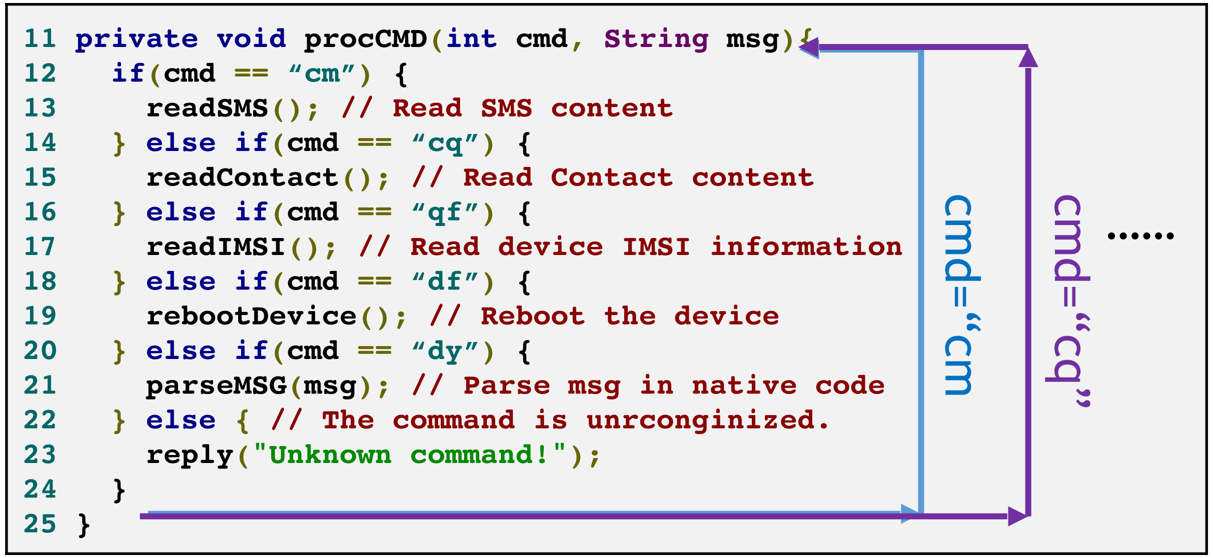

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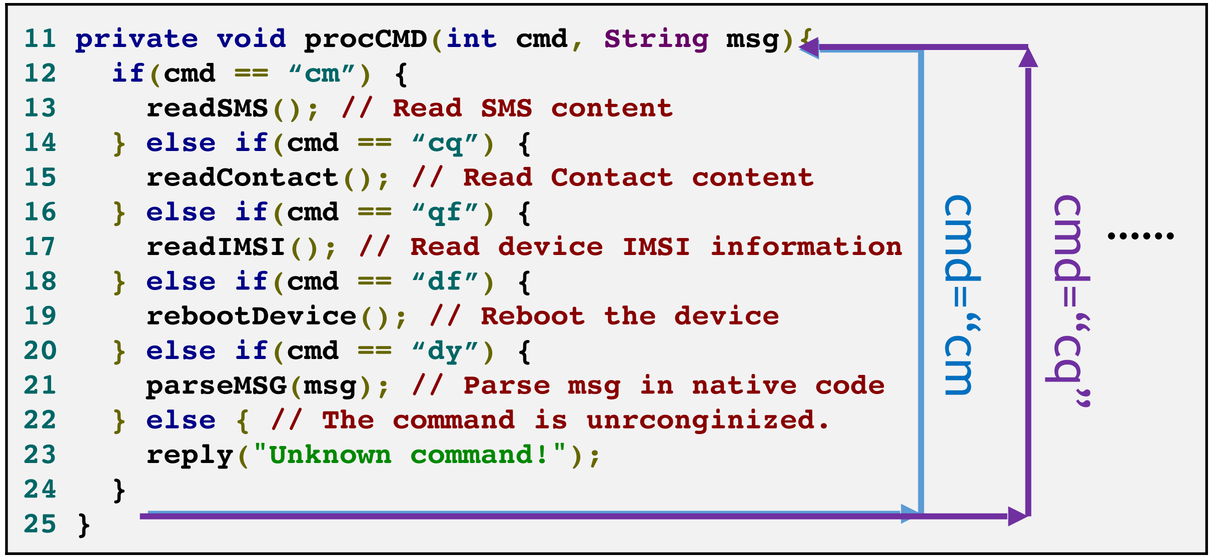

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Direct Execution

Force an app execute a path without input

Path Exploration

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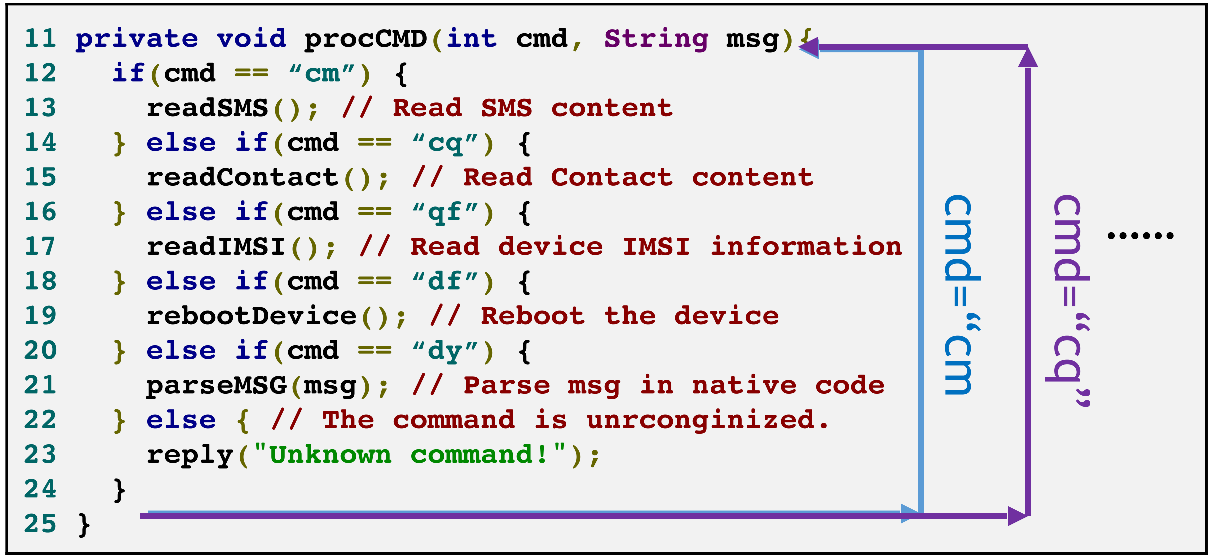

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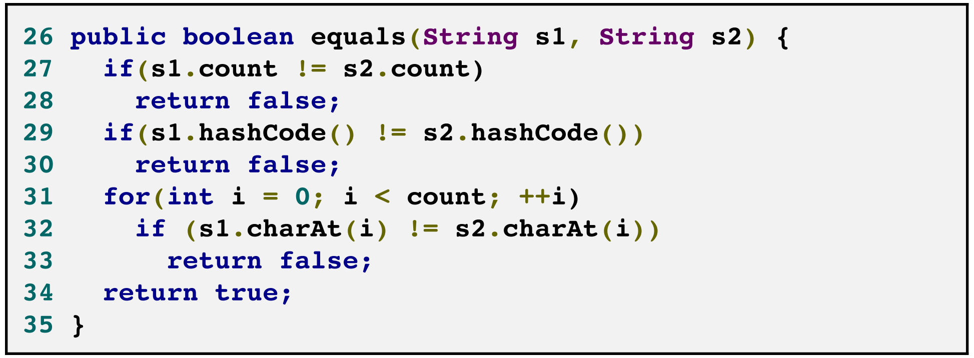

```
public boolean equals(String s1, String s2) {
  if(s1.count != s2.count)
    return false;
  if(s1.hashCode() != s2.hashCode())
    return false;
  for(int i = 0; i < count; ++i)
    if (s1.charAt(i) != s2.charAt(i))
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Path Exploration

In-memory optimization：

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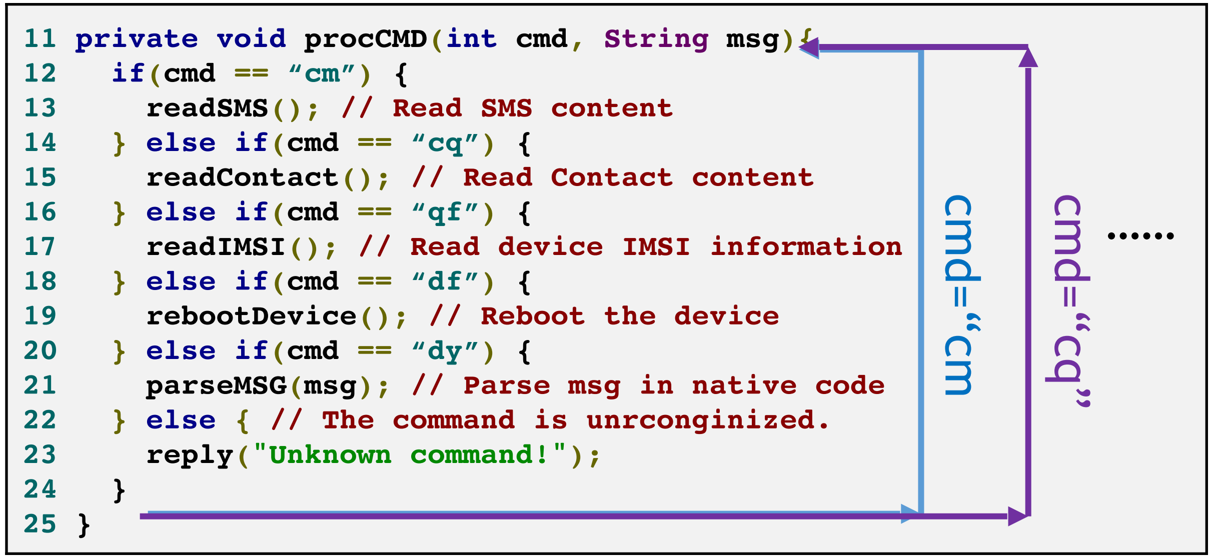

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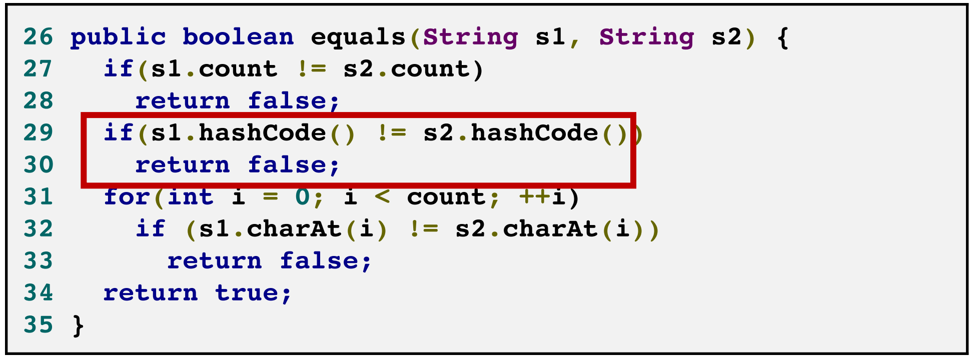

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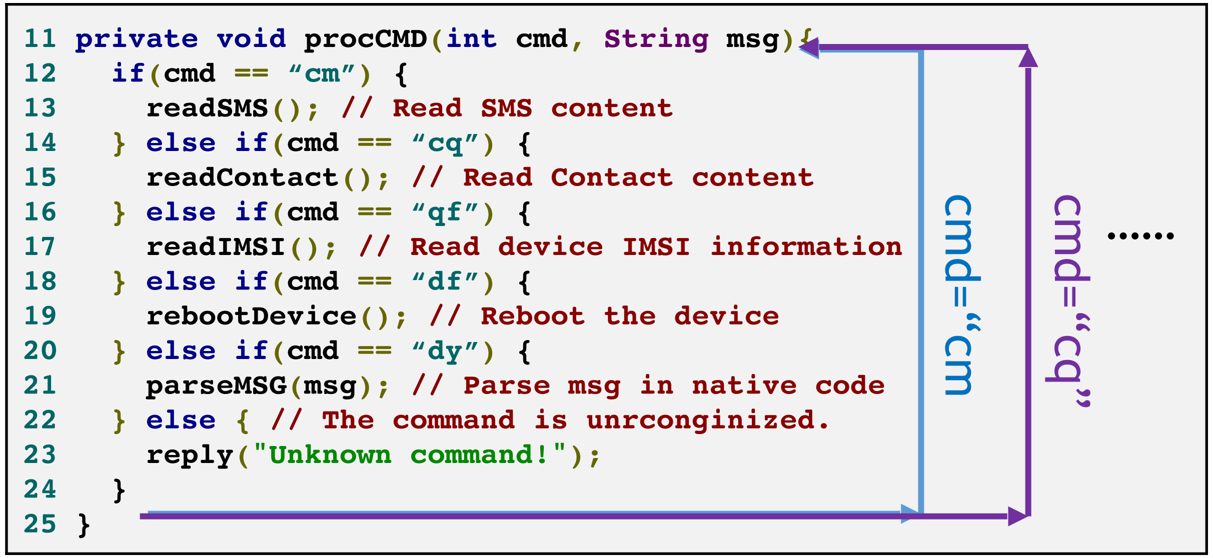

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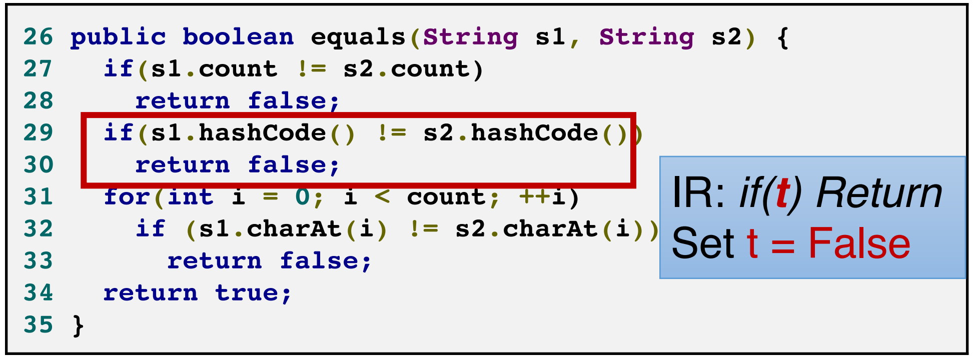
Direct Execution

Force an app execute a path without input



```
public boolean equals(String s1, String s2) {
  if(s1.count != s2.count)
    return false;
  if(s1.hashCode() != s2.hashCode())
    return false;
  for(int i = 0; i < count; ++i)
    if (s1.charAt(i) != s2.charAt(i))
      return false;
  return true;
}
```

IR: *if(**t**) Return*

Set t = False

Agenda

- ❑ Motivating Example
- ❑ The New Android Runtime (ART)
- ❑ Malton
- ❑ **Evaluation**
- ❑ Conclusion

Discovering Sensitive Operations

Behavior	CopperDroid	DroidBox	Malton
Personal Info	435 (85.0%)	135 (26.4%)	511 (99.8%)
Network access	351 (68.5%)	211 (41.2%)	445 (86.9%)
File access	438 (85.5%)	509 (99.4%)	512 (100%)
Phone call	52 (10.1%)	1 (0.2%)	59 (11.5%)
Send SMS	26 (5.1%)	15 (2.9%)	28 (5.5%)
Java code loading	NA	509 (99.4%)	512 (100%)
Anti-debugging	4 (0.8%)	NA	4 (0.8%)
Native code loading	NA	NA	160 (31.2%)

- 512 samples and results of CopperDroid are downloaded from its web servers.

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Result: Malton can capture more sensitive behaviors thanks to its on-device and cross-layer inspection.

Path Exploration

Command	Detected behavior	No. of executed blocks
“cq”	Read information SMS contents, contacts, device model and system version, then send to 292019159c@fcvh77f.com with password “aAaccvv11” through SMTP protocol.	32k/20443k
“qf”	Send SMS to all contacts with no SMS content.	7k/20537k
“df”	Send SMS to specified number, and both the number and content are specified by the command SMS.	5k/22970k
“zy”	Set unconditional call forwarding through making call to “**21* targetNum%23”.	8k/22848k
“by”	Set call forwarding when the phone is busy through making call to “%23%23targetNum%23”.	15k/20639k
“ld”, “fd”, “dh”, “cz”, “fx”, “sx”, “dc”, “bc”	Modify the its configuration file zzxx.xml.	5k-18k/20403k-20452k
Others	Tell the controller the command format is error by replying an SMS.	15k/20443k

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Without in-memory optimization: 22,970k

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Result: Malton can explore paths effectively and efficiently because of the in-memory optimized concolic execution.

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- ❑ Evaluation
- ❑ **Conclusion**

1

Propose and develop Malton, a novel on-device non-invasive analysis tool for ART.

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3. In future, we will automate the in-memory optimisation and the recovery from crashes during direct execution.

Thank
You!!!