Mobile Security: Framework Analysis

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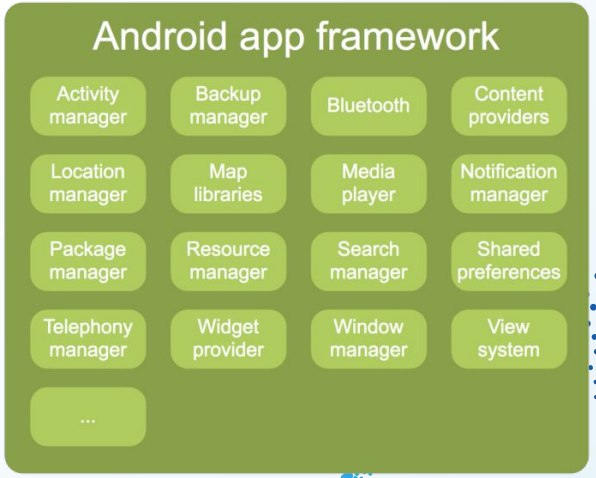
Outline

- Research paper:
  - EdgeMiner: Automatically Detecting Implicit Control Flow Transitions through the Android Framework
  - Kratos: Discovering Inconsistent Security Policy Enforcement in the Android Framework



EdgeMiner: Automatically Detecting Implicit Control Flow Transitions through the Android Framework

Yinzhi Cao, Yanick Fratantonio, Antonio Bianchi, Manuel Egele, Christopher Kruegel, Giovanni Vigna, and Yan Chen

NDSS 2015

Introduction

- Static analysis has been used for security and privacy
- Many analyses rely on the control flow graph
- Challenge:
  - ignoring the framework ⇒ incorrect control flow
    - common cause for imprecision: ‘callbacks’, e.g., onClick
  - analyzing the framework ⇒ 8.6 million lines of code
    - no existing research

Motivating Example

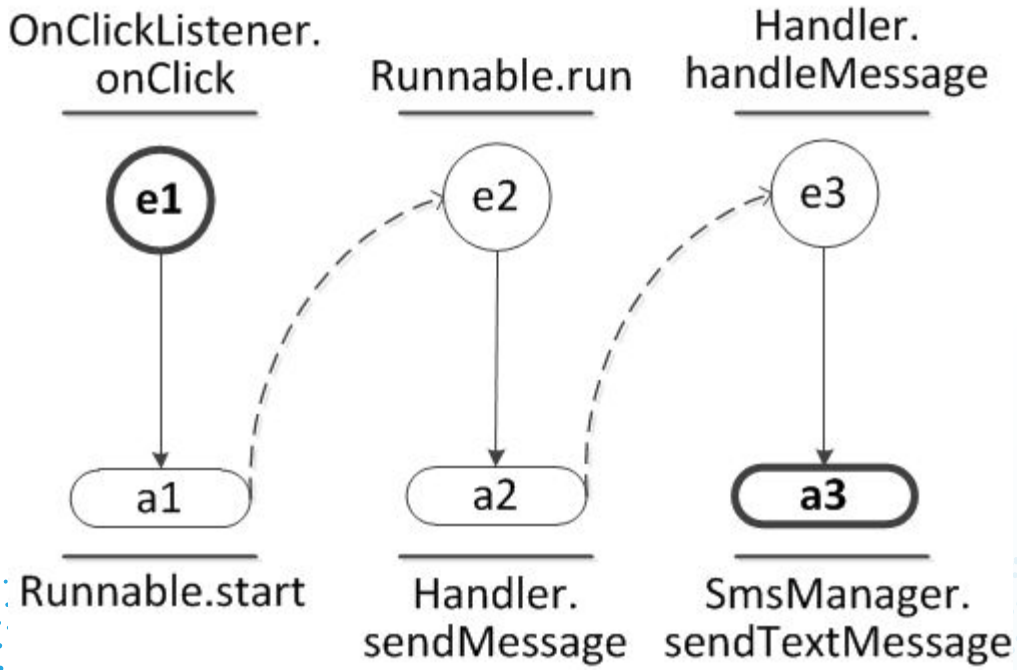
```
1 public class MainClass {
2       static String url;
3       public static void main(String[] args) {
4               MalComparator mal = new MalComparator();
5               MainClass.value = 42
6               Collections.sort(list, mal);
7               sendToInternet(MainClass.value);
8       }
9  }
10 public class MalComparator implements Comparable<Object> {
11    public int compare(Object arg0, Object arg1) {
12       MainClass.value = GPSCoords
13       return 0;
14    }
15}
```

Privacy leakage is up to the value of MainClass.value.

Existing Approaches

- Whole program analysis
  - state explosion
  - redundant efforts (slow-down of static analysis)
- Summary-based analysis
  - extensive manual efforts
    - incomplete due to the high volume of callbacks
    - heuristic summarization: inaccurate

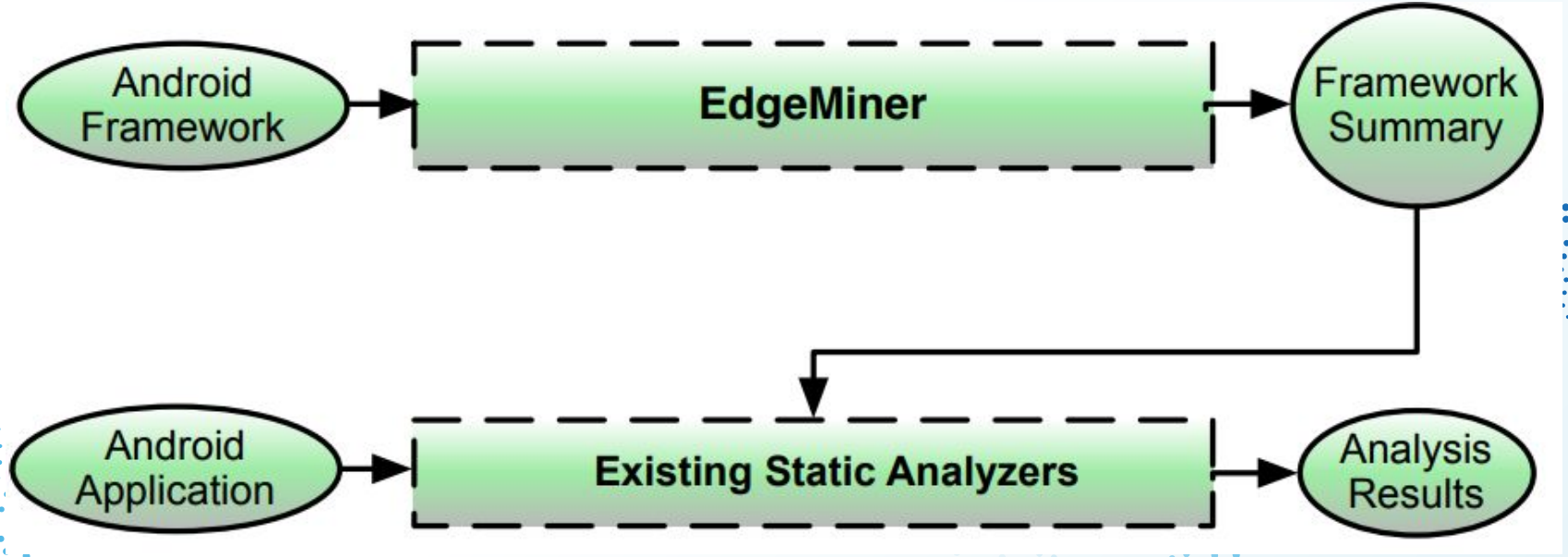
Existing Approaches




```
//Ljava/util/LinkedList;.add
{
    signature = "<java.util.LinkedList: boolean add(java.lang.Object)>";

    stod = new LinkedHashMap<Integer, List<Integer>>();

    source = new Integer(0);
    dests = new ArrayList<Integer>();
    dests.add(new Integer(thisObject));
    stod.put(source, dests);

    summary.put(signature, stod);
}
```

EdgeMiner

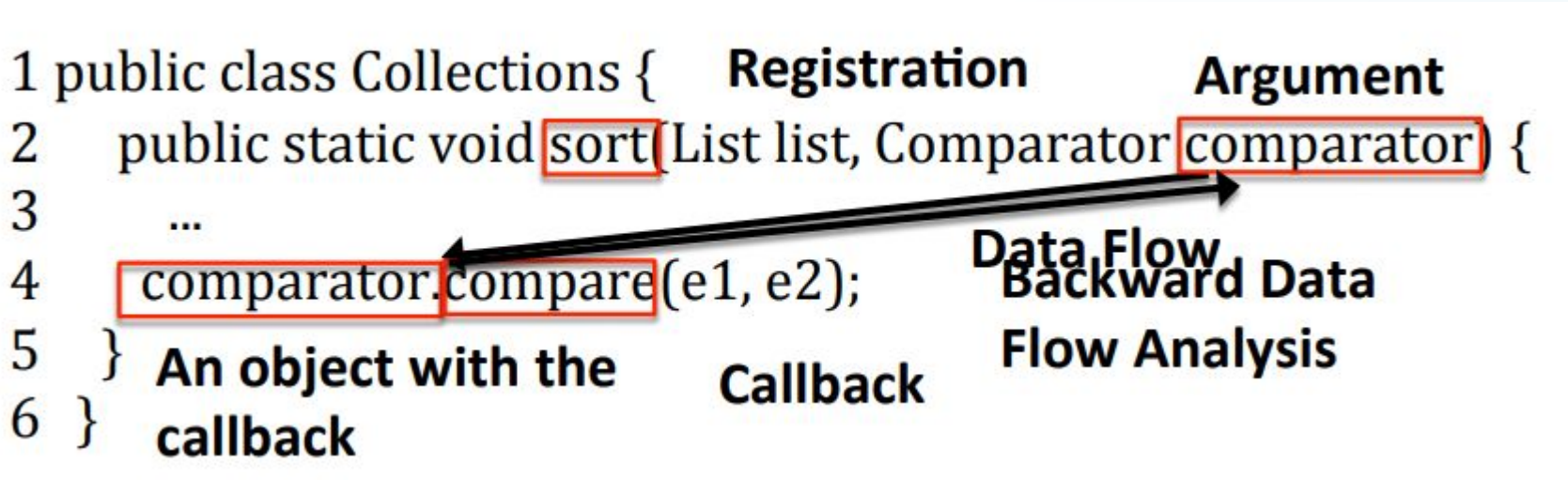
- Summarize framework: list of registration-callback pairs



Concepts

- Callbacks
  - necessary condition: a framework method that can be overridden by an application method
- Registration
  - necessary condition: a framework method that is invokable from the application space

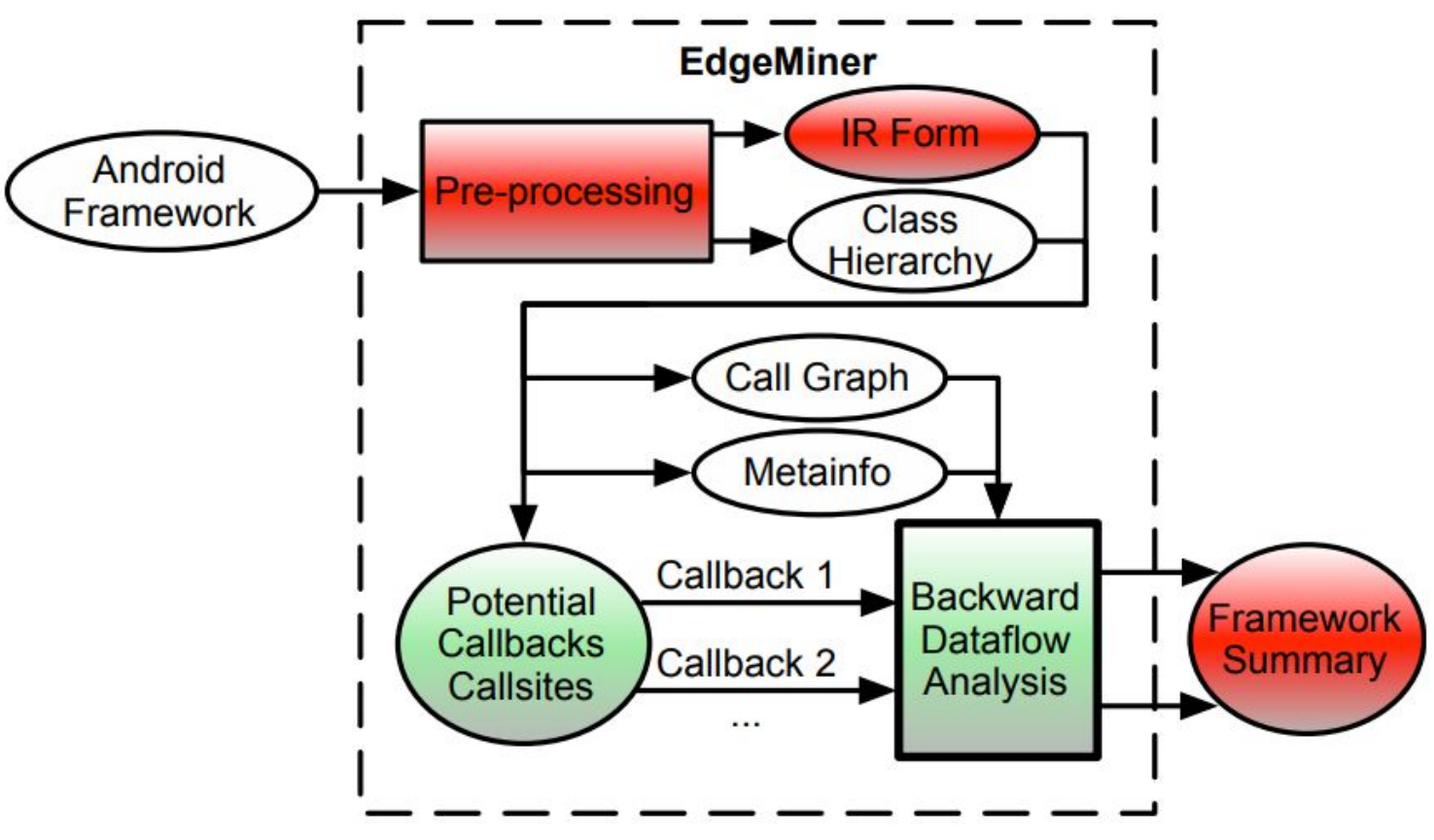
A Data Flow


1 public class Collections {
2 public static void sort(List list, Comparator comparator) {
3 ...
4 comparator.compare(e1, e2);
5 }
6 }
Registration
Argument
Data Flow
Backward Data Flow Analysis
An object with the callback
Callback

Implementation

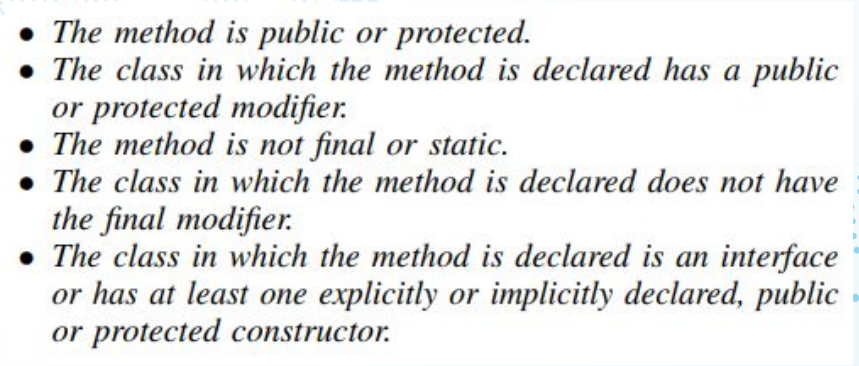
- ROP intermediate representation (IR)
  - Well-suited for static analysis
  - SSA format
  - Integral part of Android SDK
- EdgeMiner
  - built on top of ROP
  - performs backward dataflow analysis
  - summarizes implicit control flows through framework

System Architecture



Implementation

- Preprocessing
  - transforms individual methods into SSA format
  - extracts class hierarchy
    - need for generating an over-approximation of the call graph
  - generates call graph
    - necessary for data-flow analysis
- Potential callback callsites



- *The method is public or protected.*
- *The class in which the method is declared has a public or protected modifier.*
- *The method is not final or static.*
- *The class in which the method is declared does not have the final modifier.*
- *The class in which the method is declared is an interface or has at least one explicitly or implicitly declared, public or protected constructor.*

Evaluation

- Tested on Android 2.3, 3.0 and 4.2 frameworks
- Number of registrations and callbacks

Android Version	# Registrations	# Callbacks	# Pairs
2.3 (API 10)	10,998	11,044	1,926,543
3.0 (API 11)	12,019	13,391	2,606,763
4.2 (API 17)	21,388	19,647	5,125,472

Accuracy

- False negative
  - compare with dynamic approach
    - incomplete but accurate
  - 8,195 randomly selected applications
  - 6,906 registration-callback pairs
  - EdgeMiner finds all pairs
- False positive
  - against manual inspection
  - 8 FP out of 200 pairs

Improving Static Analyzer

- Integration with FlowDroid
  - synchronous callbacks: inline invocation
    - e.e., collections.sort and Comparator.compare
  - asynchronous callbacks: delayed invocation
    - e.g., setOnClickListener and onClick
- Patterns of callbacks used by FlowDroid and identified by

Pattern	# FlowDroid	# EdgeMiner
Listener	155	576
Callback	19	319
On	3	509
None of the above	4	18,243
Total	181	19,647

Improving Static Analyzer

- Run 9 new apps in TaintDroid
  - 4 verified, 2 crash and 3 no leak
- Incorrect call graph → missed privacy leaks
- Performance
  - 34.7 seconds one-time loading
  - only 1.85% overhead added to Flowdroid

Tool	FlowDroid	FlowDroid + EdgeMiner
# Apps with ≥ 1 privacy leak	285	294 (285 + 9)
# Privacy leaks (in total)	46,586	51,418
# Apps timeout	48	48

Kratos: Discovering Inconsistent Security Policy Enforcement in the Android Framework

Yuru Shao, Jason Ott, Qi Alfred Chen, Zhiyun Qian, Z. Morley Mao

NDSS 2016

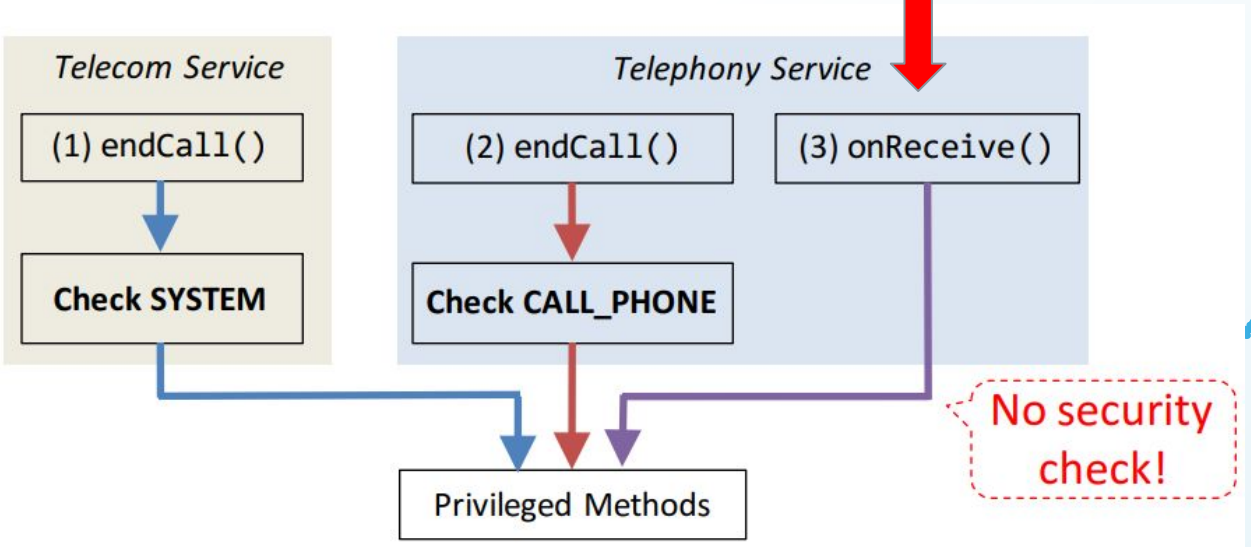
Security Policy Enforcement

- Security policies regulate access to
  - sensitive data
  - system resources
  - privileged operations
- Policies need to be correctly enforced

Motivation

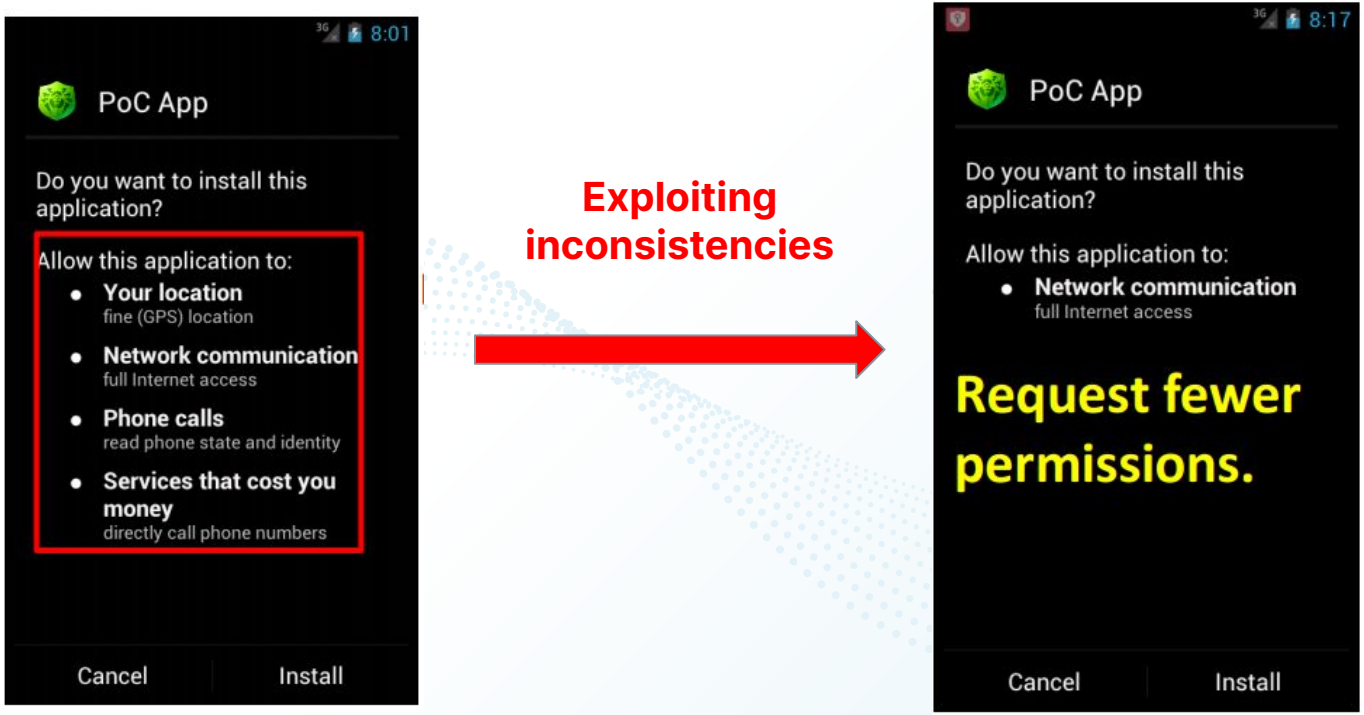
The enforcement of a security policy on different code paths can be inconsistent

- Inconsistencies do exist
- According to the Android documentation
  - apps that hold a CALL_PHONE permission can end phone calls



Security Implication

- Privilege escalation



Existing Research

- Inconsistent security policy enforcement is also found in SELinux and Xen [AutoISES Usenix Sec'08]
  - unauthorized user account access
  - permanent data loss
- No solution for Android framework
  - prior work is OS specific
  - Android has no explicitly defined policies

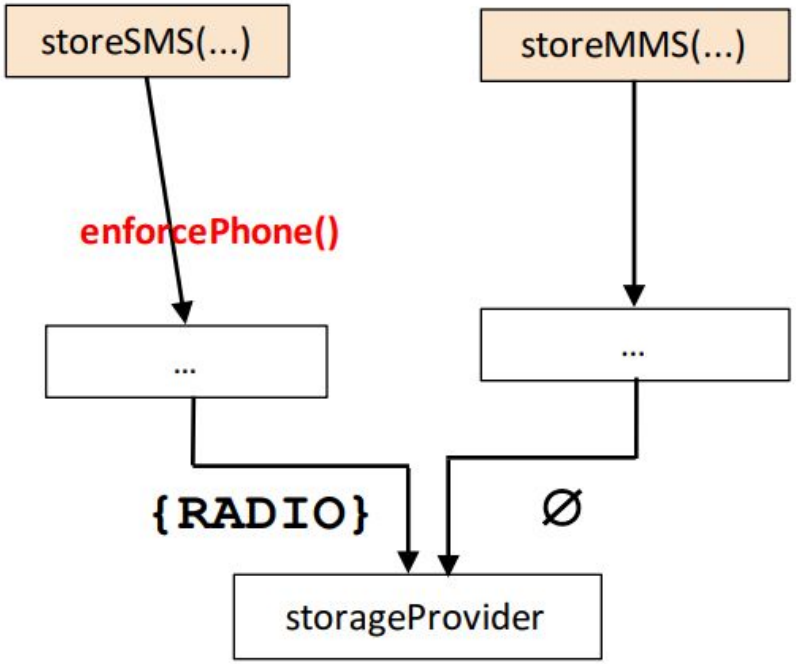
Problem Statement

- Focus on the Android framework
- Seek to answer the following question:
  - How can we systematically detect inconsistent security policy enforcement *without any knowledge of the policies*?

Approach

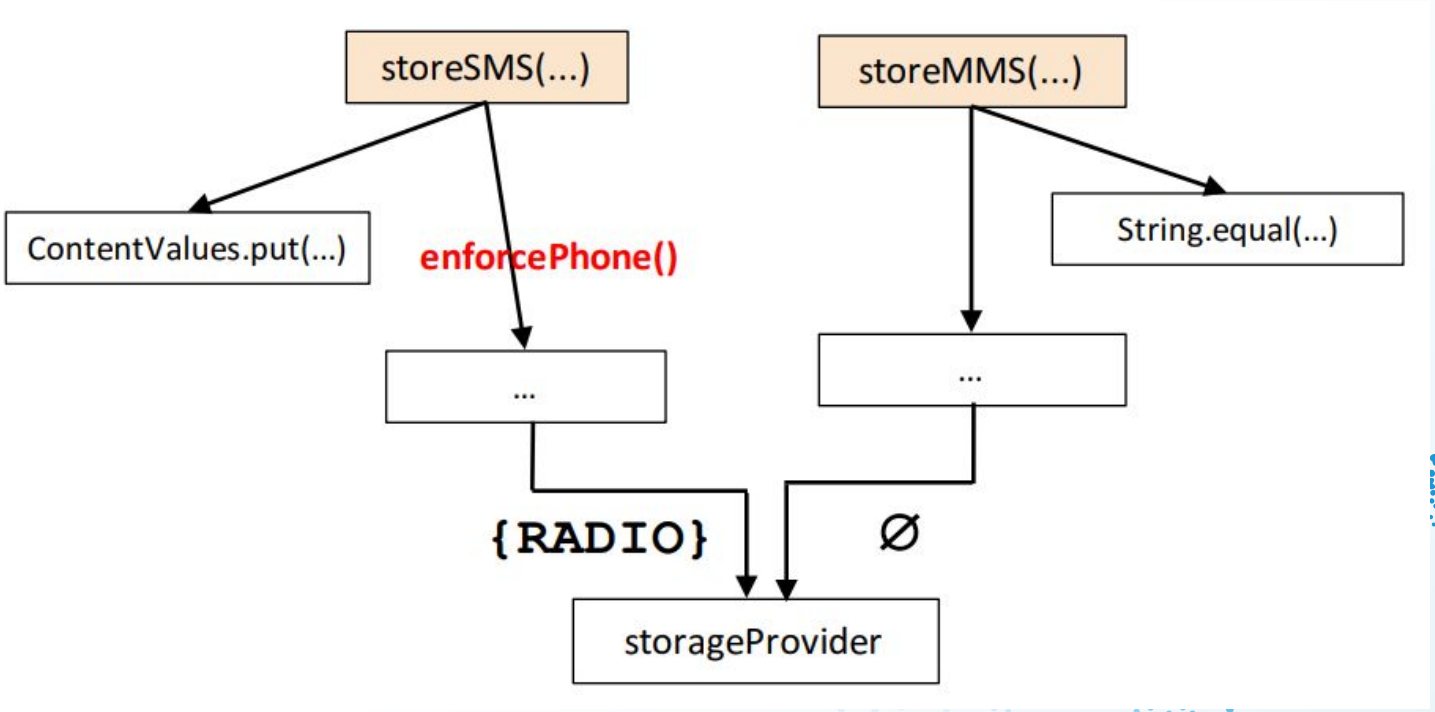
- Discover app-accessible service interfaces that have overlaps in functionality
  - expected to have consistent security enforcement
- Perform a differential analysis on security checks that two overlapping interfaces employ

Differential Analysis



enforcePhone() checks if the caller's UID is 1001 (RADIO)

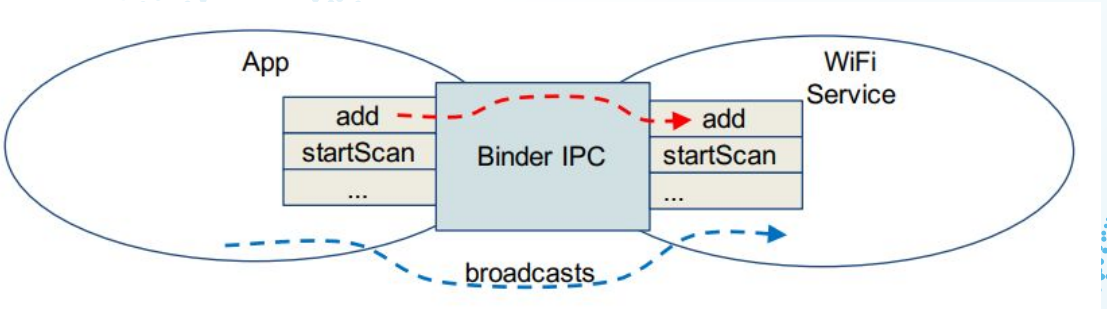
Pruning



enforcePhone() checks if the caller's UID is 1001 (RADIO)

App-accessible Service Interfaces

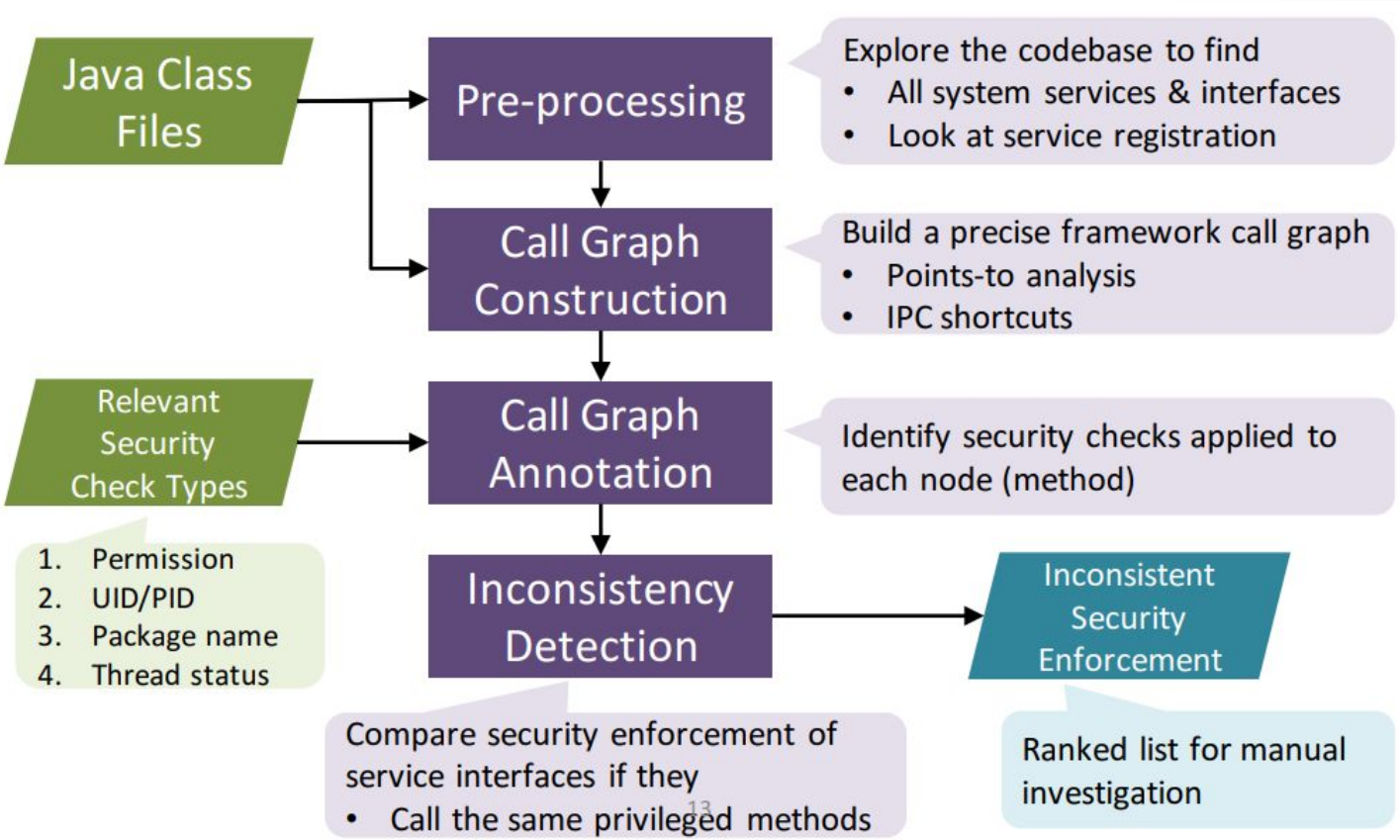
- Analysis scope:
  - system services perform enforcement
- Service interfaces
  - AIDL (Android interface definition language) methods
  - broadcast receivers



Security Checks

- Security enforcement:
  - a set of security checks
- Kratos formulates 4 types of checks
  - permission check
  - UID/PID check
  - package name check
  - thread status check

Kratos Design



Implementation

- Support AOSP and customized frameworks
  - obtain java classes from
    - intermediate building output (AOSP)
    - decompiled dex files (customized)
- Build a precise framework call graph
  - points-to analysis using Spark
  - create an artificial and static entry point including app
    app-accessible service interfaces
- Perform data-flow analysis
  - identify security check methods
  - collect system services

Evaluation

- 6 different Android codebases
  - AOSP 4.4, 5.0, 5.1 and M preview
  - HTC one, Samsung Galaxy Note 3
- Accuracy

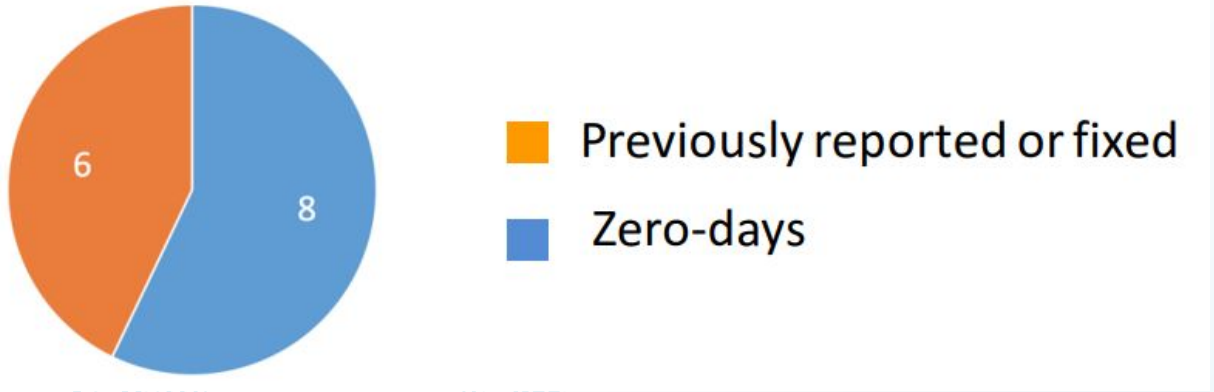
Codebase	# Inconsistencies	# TP	# FP	Precision	# Exploitable
Android 4.4	21	16	5	76.2%	8
Android 5.0	61	50	11	82.0%	11
Android 5.1	63	49	14	77.8%	10
M Preview	73	58	15	79.5%	8
AT&T HTC One	29	20	9	69.0%	8
T-Mobile Samsung Galaxy Note 3	128	102	26	79.7%	10

Evaluation

- False positive
  - two interfaces are not equivalent in functionality
  - points-to analysis $\Longrightarrow$ over-approximated results
- not all inconsistencies are exploitable
  - difficult to construct valid arguments
  - difficult to trigger particular privileged methods

Evaluation

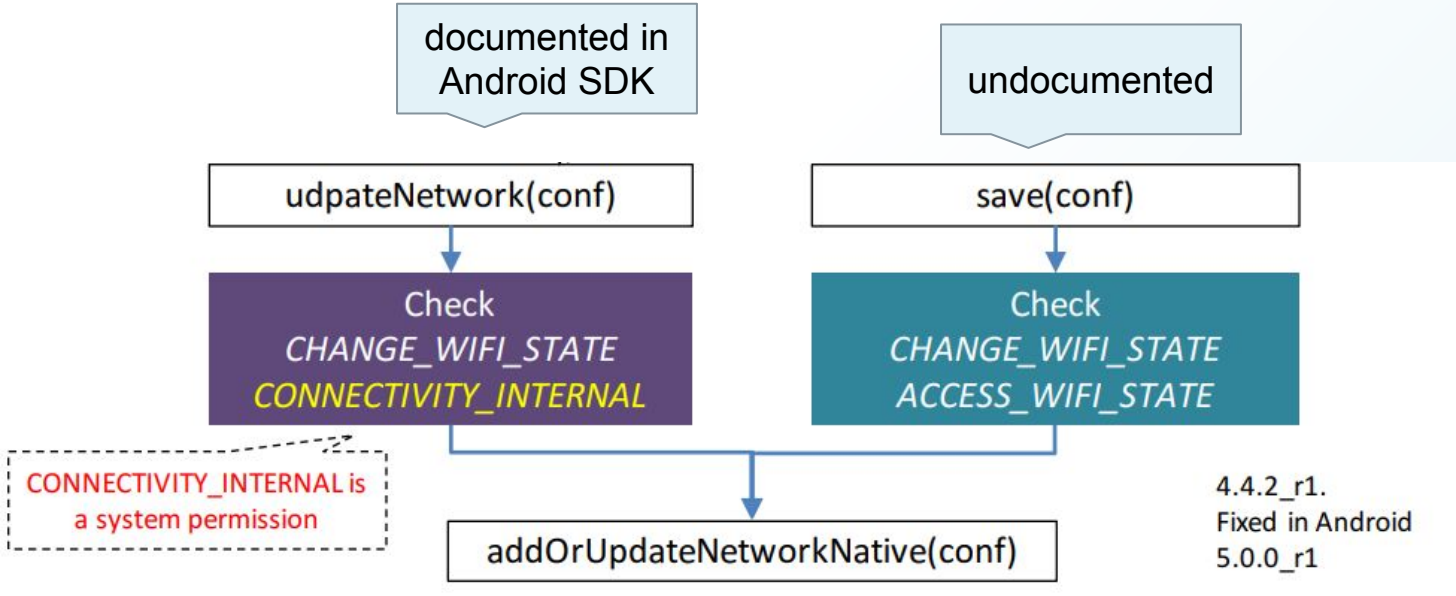
- Found 14 vulnerabilities



- 5 out of 14 affect all codebases
- bug reports confirmed by Google

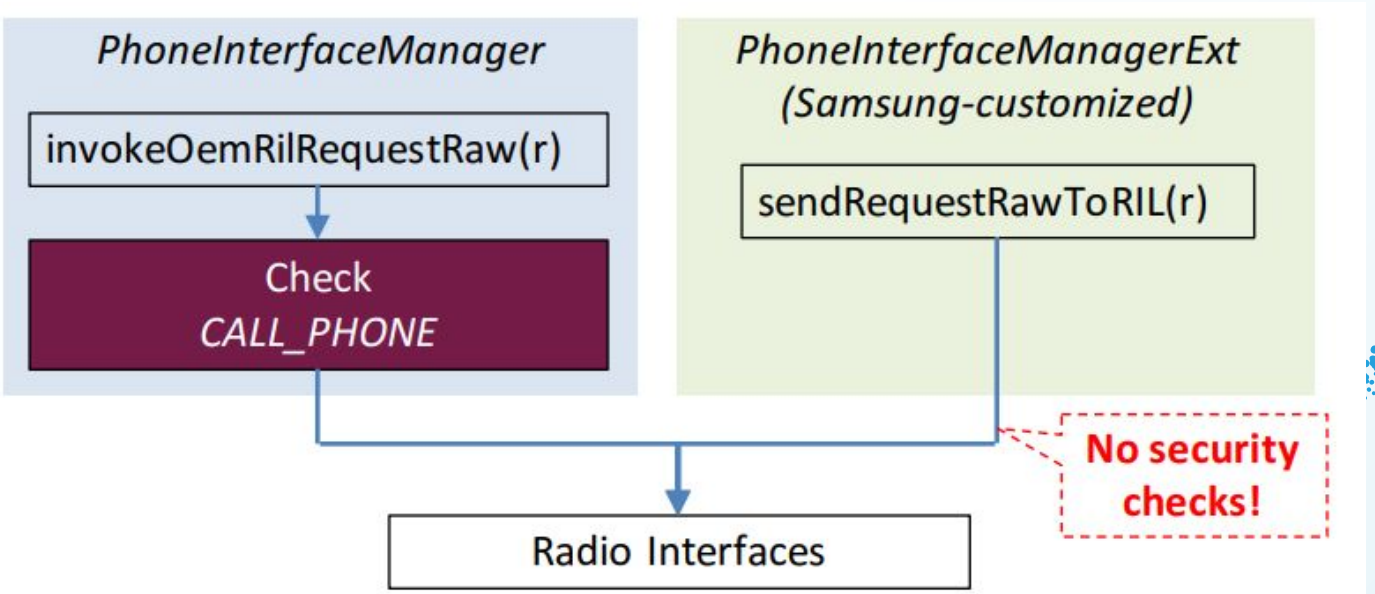
Case Study 1

- Bypass system permission to change HTTP proxy settings



Case Study 3

- Send arbitrary requests to the radio hardware without any permission



Other Observations

- 11 vulnerable interfaces are hidden to apps
  - not available in the Android SDK
  - invoke using Java reflection
- AOSP frameworks
  - new system services introduce new inconsistencies
  - lead to new vulnerabilities
- Customized frameworks
  - Samsung added many system services
    - introduced 2 additional vulnerabilities
    - 1 vulnerability in AOSP was fixed

Thank you!

Questions?