CS 563
Mobile OS & Device Security

Advanced Computer Security

CS 563

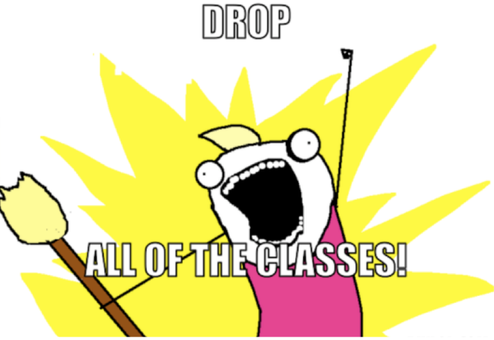
University of Illinois at Urbana-Champaign

Presentation by: Güliz Seray Tuncay

Administrative

Announcements:
- Reaction paper was due today (and all classes)
- Feedback for reaction papers soon
- "Preference Proposal" Homework due 9/24

Learning Objectives:
- Background of mobile OSes
- Study the security fundamentals of Android OS
- Discuss privilege escalation and web attacks

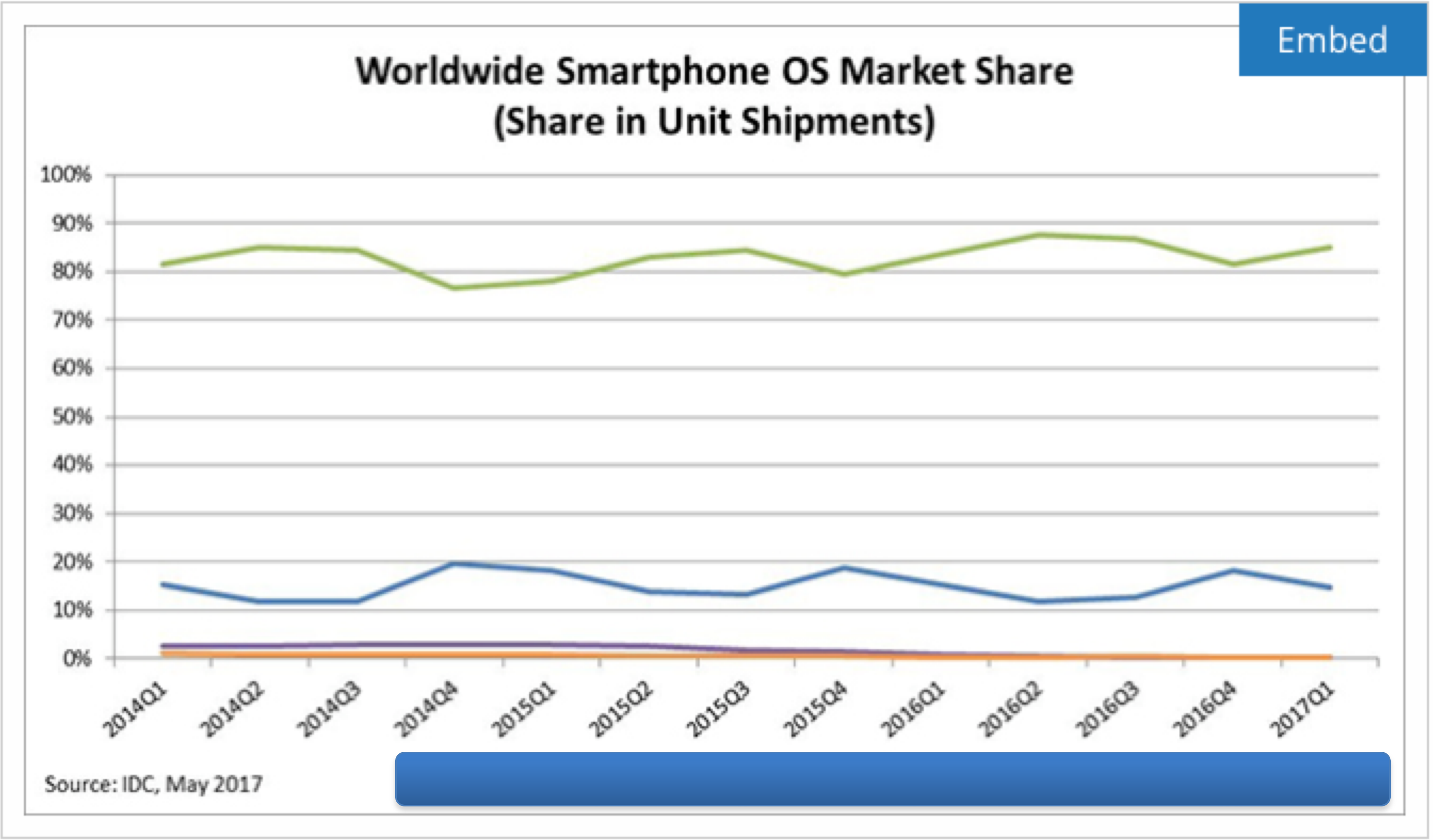


Reminder: Please put away (backlit) devices at the start of class

Mobile Phone Evolution

- Basic Phone
- Phone with SIM Application Toolkit (STK)
  - Tiny programs stored on GSM SIM cards
  - Typically enable value-added features
- Feature Phones
  - Extra features on the phone firmware itself
  - Typically provided by the phone manufacturer
- Smart Phones
  - API available that enables third-party apps

Growth of Mobile OS



Mobiles, Tablets, PC sales

Worldwide Device Shipments by Device Type, 2016-2019 (Millions of Units)

Device Type	2016	2017	2018	2019
Traditional PCs (Desk-Based and Notebook)	220	204	193	187
Ultramobiles (Premium)	50	59	70	80
Total PC Market	270	262	264	267
Ultramobiles (Basic and Utility)	169	160	159	156
Computing Device Market	439	423	423	423
Mobile Phones	1,893	1,855	1,903	1,924
Total Device Market	2,332	2,278	2,326	2,347

Source: Gartner (January 2018)

PC versus Smart Phones

- Why worry specifically about mobile OS security?
  – Smart phones are computing platforms similar to desktop OS: why not use the same principles?
- PC versus Smart Phones
  – Users: Root privileges typically not given to user
  – Persistent Personal Data
    - Input is cumbersome, so credentials are frequently stored
  – Battery performance is an issue
    - Implementing some security features may drain battery
  – Network usage can be expensive

PC versus Smart Phones (cont'd)

- Unique features in Smart Phones
  - Location Data
    - GPS and Wifi-based tracking
  - Premium SMS Messages (expensive)
  - Making and recording phone calls
  - Logs of previously sent SMS
  - Different authentication mechanisms
    - Fingerprint reader (available across platform)
    - Face Unlock (Android 5.0)
    - Trusted Places, Devices, Voice (Android 5.0)
  - Specific markets for mobile apps

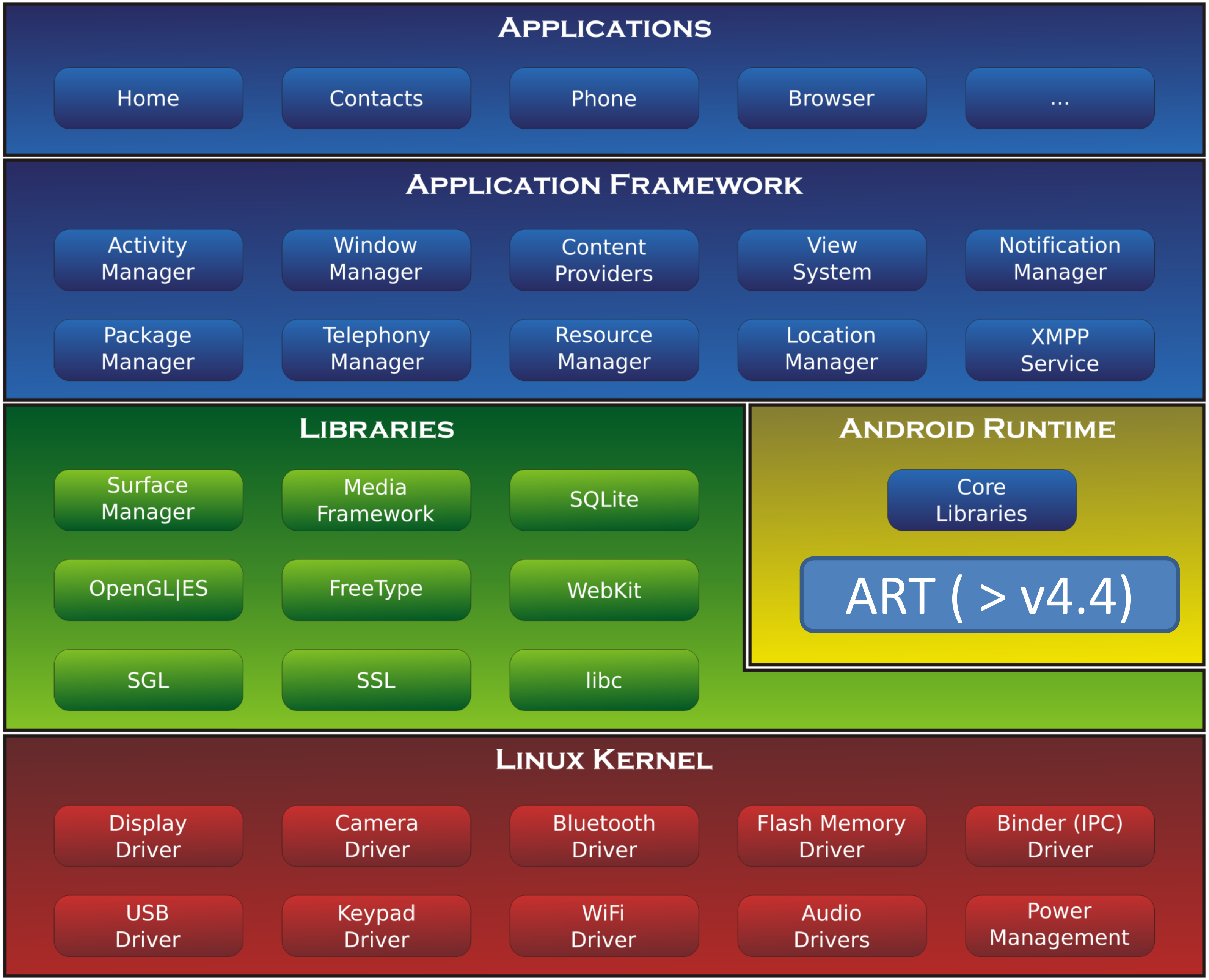
Mobile OS Security Frameworks

- Covered
  - Android Security Model
- Not Covered
  - Apple iOS
  - Windows OS
  - Blackberry

Android

Android

- Platform outline:
  - Linux kernel
  - Embedded Web Browser
  - SQL-lite database
  - Software for secure network communication
    - Open SSL, Bouncy Castle crypto API and Java library
  - Java platform for running applications
  - C language infrastructure
  - Also: video APIs, Bluetooth, vibrate phone, etc.


Applications
Home
Contacts
Phone
Browser
...
Application Framework
Activity Manager
Window Manager
Content Providers
View System
Notification Manager
Package Manager
Telephony Manager
Resource Manager
Location Manager
XMPP Service
Libraries
Surface Manager
Media Framework
SQLite
OpenGL|ES
FreeType
WebKit
SGL
SSL
libc
Android Runtime
Core Libraries
ART (> v4.4)
Linux Kernel
Display Driver
Camera Driver
Bluetooth Driver
Flash Memory Driver
Binder (IPC) Driver
USB Driver
Keypad Driver
WiFi Driver
Audio Drivers
Power Management

Android Market (Google Play Store)

- Self-signed apps
- Open market
  - Not rigorously reviewed by Google (unlike Apple)
  - Bad applications may show up on market
  - Malware writers can get code onto platform: Self-signed applications are possible
    - shifts focus from remote exploit to privilege escalation

Android Application Structure

- 4 components
  - Activity – one-user task
    - E.g., scroll through your inbox
  - Service – Java daemon that runs in background
    - E.g., application that streams an mp3
  - Broadcast receiver
    - "mailboxes" for messages from other applications
  - Content provider
    - Store and share data using a relational database interface
- Activating components
  - Via Intents

Android Intents

- Message between components in same or different app
- Intent is a bundle of information, e.g.,
  - action to be taken
  - data to act on
  - category of component to handle the intent
  - instructions on how to launch a target activity
- Routing can be
  - Explicit: delivered only to a specific receiver
  - Implicit: all components that have registered to receive that action will get the message

Android Manifest File

- Declarations
  - Components
  - Component capabilities
    - Intent filters
    - Permissions etc.
  - App requirements
    - Permissions
    - Sensors etc.

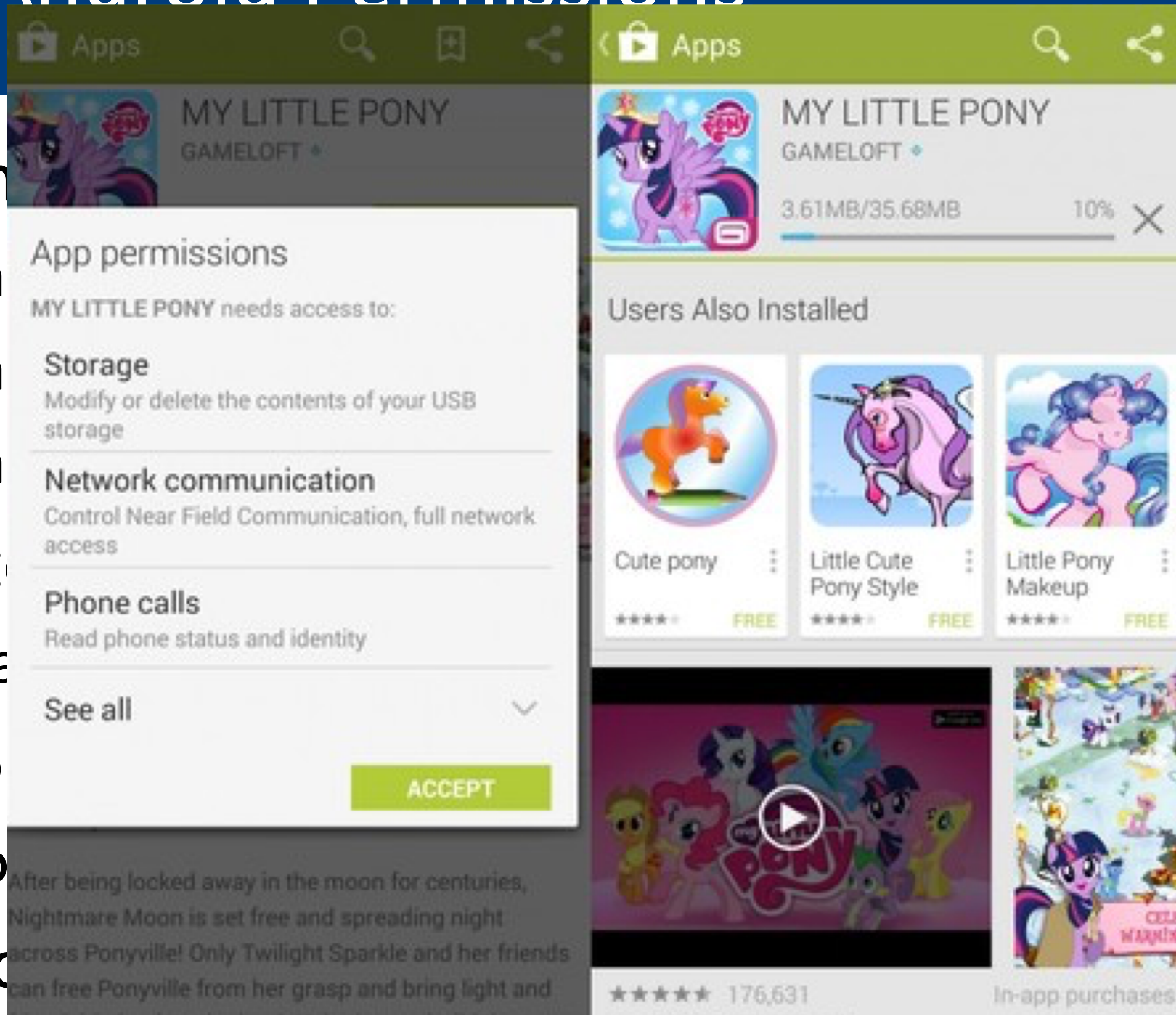
```xml
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
    package="com.gulizseray.provider.infoprovider">
    <uses-permission
        android:name="android.permission.RECORD_AUDIO" />
    <uses-feature
        android:name="android.hardware.microphone"
        android:required="true"/>
    <application
        android:allowBackup="true"
        android:icon="@mipmap/ic_launcher"
        android:label="InfoProvider"
        android:supportsRtl="true"
        android:theme="@style/AppTheme">
        <activity
            android:name=".MainActivity"
            android:theme="@style/AppTheme.NoActionBar">
            <intent-filter>
                <action android:name="android.intent.action.MAIN" />
                <category android:name="android.intent.category.LAUNCHER" />
            </intent-filter>
        </activity>
        <service android:name=".InfoProviderService" android:exported="true"/>
    </application>
</manifest>
```

Android Permissions

- Example of permissions provided by Android
  - "android.permission.INTERNET"
  - "android.permission.READ_EXTERNAL_STORAGE"
  - "android.permission.SEND_SMS"
- Protection levels
  - Dangerous, normal, signature
- Also possible to define custom permissions
  - To enable or disable other apps to call their features
- Used to be granted at installation but…

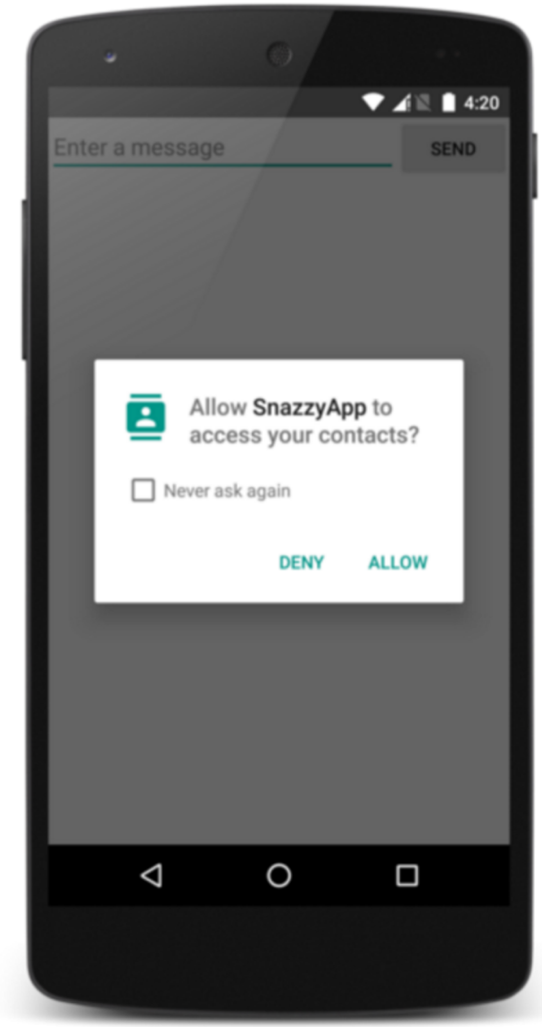
Android Permissions

- Exan d
  - “a
  - “a E”
  - “a
- Prot
  - Da
- Also
  - To tures
- Usec

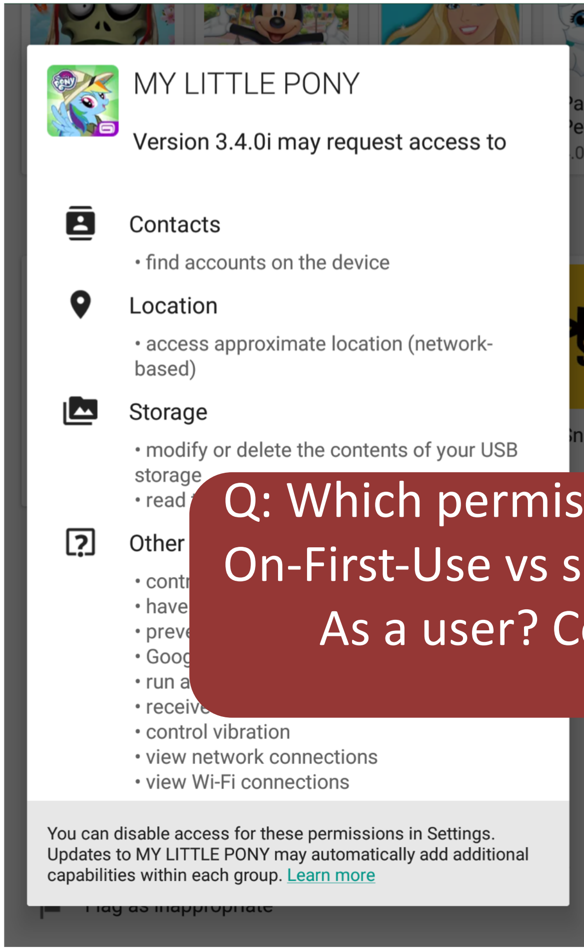


Android Runtime Permissions

- Runtime permissions
  - Dangerous permissions granted at runtime
  - Normal and signature permissions still granted at installation
  - Only valid for modern apps (API >= 23), permissions are still install time for legacy app
  - Permissions granted based on a permission group basis



Android Permission Groups



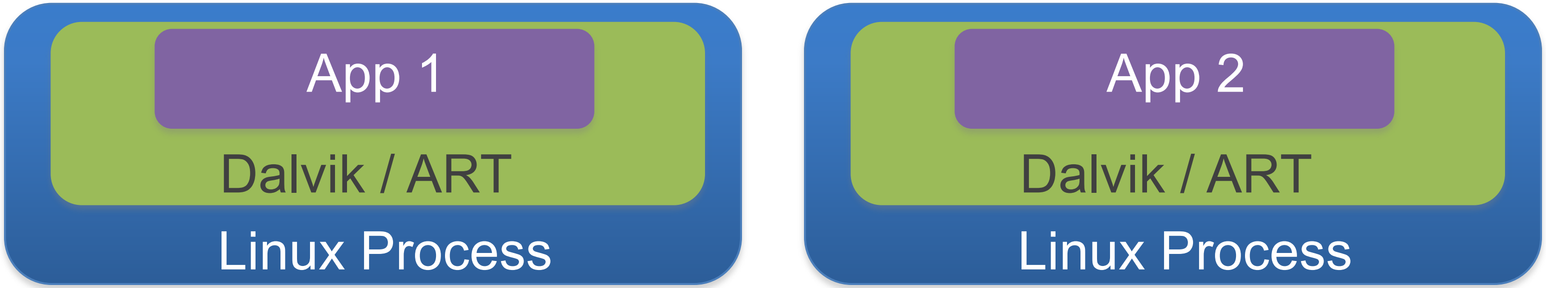
Permission Group	Permissions
CALENDAR	• READ_CALENDAR • WRITE_CALENDAR
CAMERA	• CAMERA
CONTACTS	• READ_CONTACTS • WRITE_CONTACTS • GET_ACCOUNTS
LOCATION	• ACCESS_FINE_LOCATION • ACCESS_COARSE_LOCATION
MICROPHONE	• RECORD_AUDIO
PHONE	• READ_PHONE_STATE
SENSORS	• BODY_SENSORS
SMS	• SEND_SMS • RECEIVE_SMS • READ_SMS • RECEIVE_WAP_PUSH • RECEIVE_MMS
STORAGE	• READ_EXTERNAL_STORAGE • WRITE_EXTERNAL_STORAGE

Q: Which permission model do you prefer: Installation-Time vs Ask-On-First-Use vs something else?

As a user? Complications for developers?

Isolation

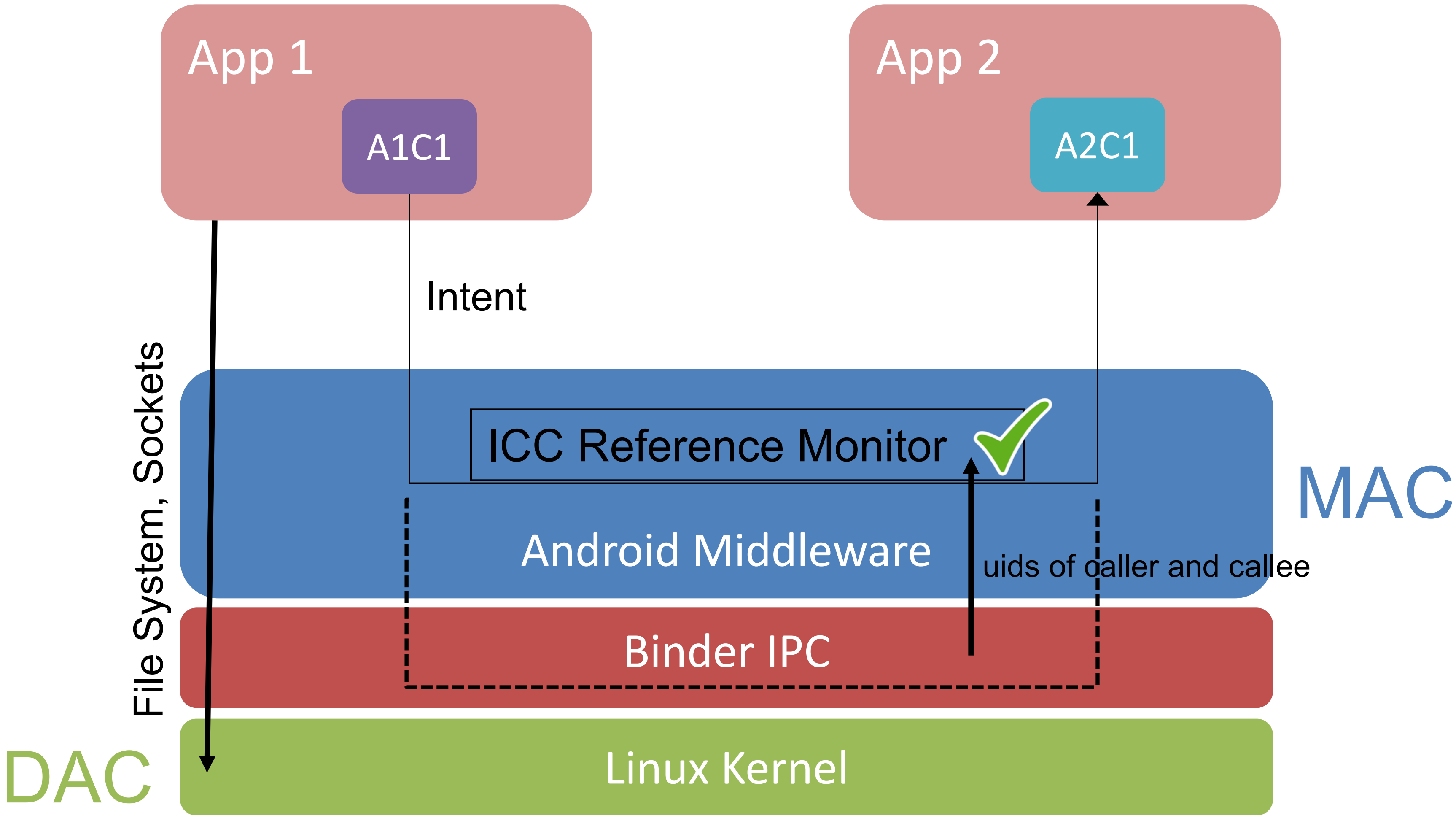
- Multi-user Linux operating system
- Each application normally runs as a different user
  - Each app has its own VM
  - Traditional linux-based permissions apply (DAC)
- Applications announce permission requirement
  - Create a whitelist model – user grants access
  - ICC reference monitor checks permissions (MAC)



Inter-component Communication

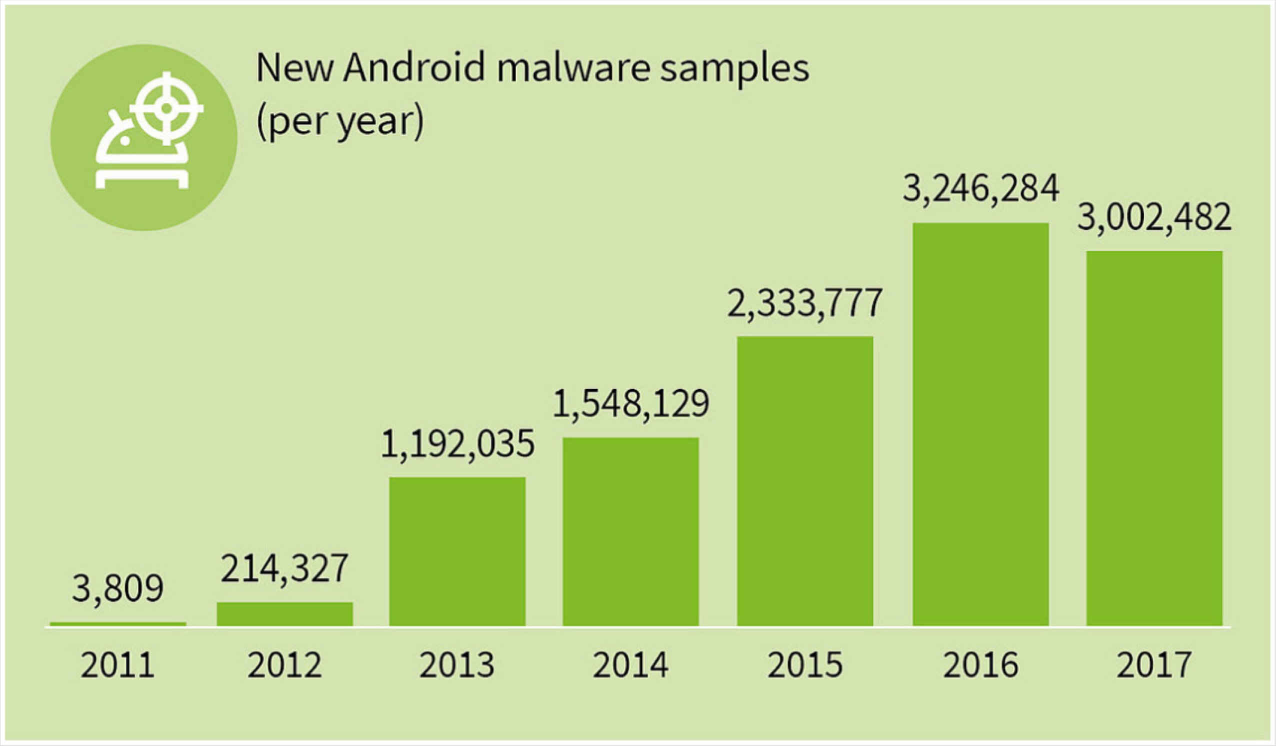
- Flexibility and reusability important for Android
  - Enable apps to work together to accomplish things
- Apps communicate through application framework
  - Intents based on Binder IPC
  - Implemented in kernel as a driver

Binder IPC & Permission Enforcement



Q: Heavily relying on IPC (Android) vs completely standalone apps (iOS, kind of)? Which one do you think is better?

Android malware



G DATA analysts are counting over 3 million new Android malware samples in 2017. 744,065 of these were discovered in the fourth quarter.

Android malware

850 million Android devices still at ri
hijack by Stagefright bug

Security researchers say fragmented manner of Android operating system restricts protections

By Danny Palmer | March 24, 2016 -- 15:31 GMT (08:31 PDT) | Topic: Security

0 f in

RECOMME

The Rise of Mac

Stagefright malware is back! ' Android bug in history' return third time and could infect a B phones

- Stagefright bug lets attackers take control of older Android h
- Notorious bug is back for a third time, security research firm
- Israel-based NorthBit security researchers seem to show the
- It only affects handsets running software older than Android being told to upgrade, and install anti-malware apps

By SARAH GRIFFITHS FOR MAILONLINE

PUBLISHED: 06:59 EDT, 21 March 2016 | **UPDATED:** 19:17 EDT, 21 March 20

G DATA analysts are counting over 3 million new Android malware samples in 2017. 744,065 of these were discover

21,636 views | Sep 14, 2017, 09:35am

Google Is Fighting A Massive Android Malware Outbreak -- Up To 21 Million Victims

Thomas Brewster Forbes Staff

Security

I cover crime, privacy and security in digital and physical forms.

Android has been hit by another big malware campaign, as criminals exploit Google's platform. Photographer: Chris Goodney/Bloomberg

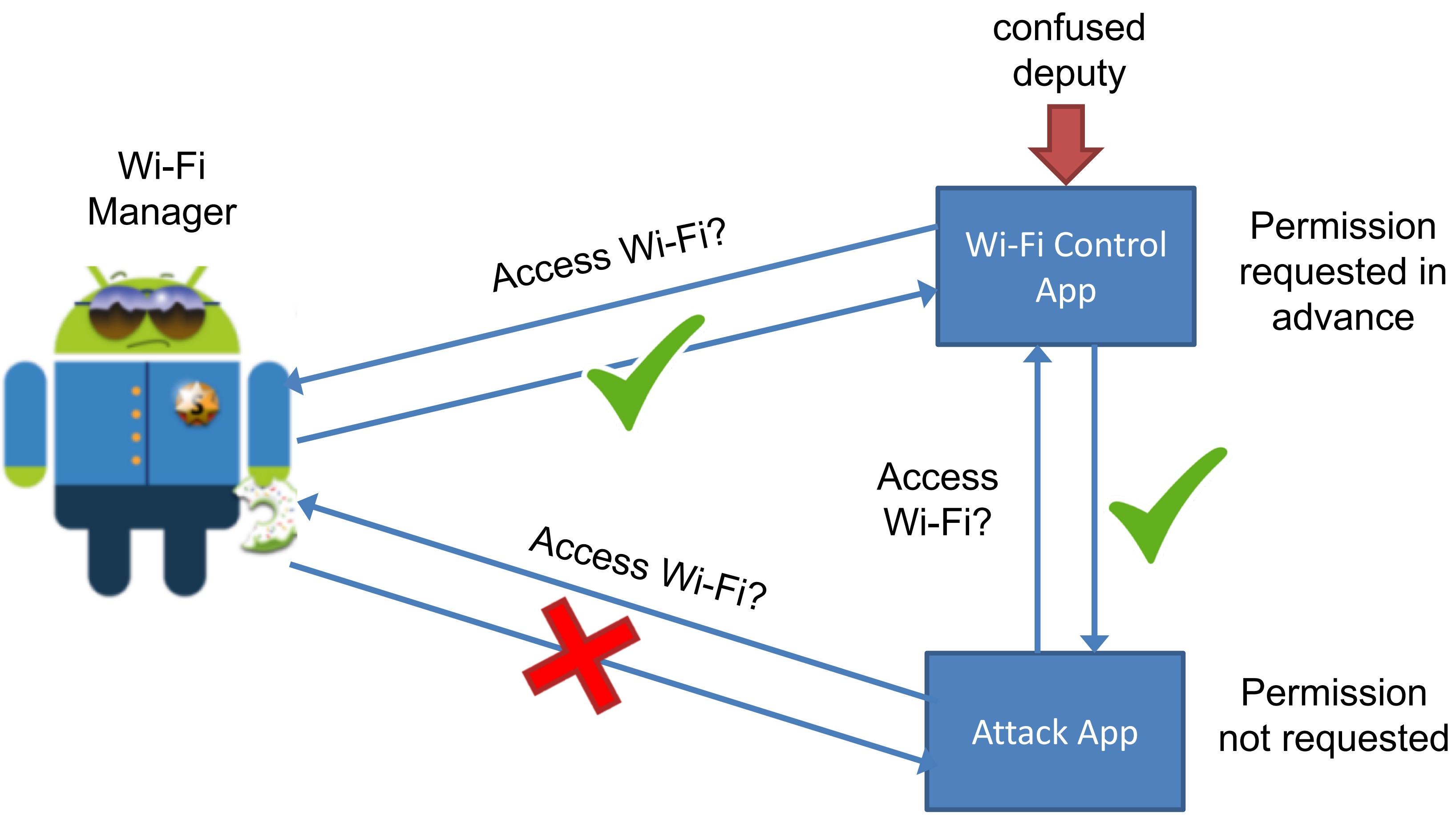
Attacks on Android

- Privilege Escalation Attacks on Android
- Web Attacks on Android
- Phishing
- Clickjacking
- Side-channel etc.

Privilege Escalation Attacks on Android

- Gaining elevated access to resources that are normally protected from an application
- 2 major classes
  - confused deputy attacks: leveraging unprotected interfaces of benign applications
    - Permission re-delegation attacks
  - collusion attacks: malicious applications merge their permissions
- Other interesting ones: mobile OS update etc.

Permission Re-delegation Attacks



Why could this happen?

- App w/ permissions exposes a public interface
  - The "deputy" app may accidentally expose privileged functionality…
  - … or intentionally expose it, but the attacker invokes it in a surprising context
    - Example: broadcast receivers in Android
  - … or intentionally expose it, attempt to reduce the invoker's authority, but do it incorrectly
    - Dynamic (programmatic) permission checks
      - checkCallingPermission(), checkCallingOrSelfPermission() etc.

[FeltUSENIX11] Felt, Adrienne Porter, et al. "Permission Re-Delegation: Attacks and Defenses." *USENIX Security Symposium*. 2011.

Public Interfaces in Android Manifest

- Via exported tag
  - <service android:name=“.WiFiService” android:exported=“true”> </service>
- Via intent filters
  - <receiver android:name=“.WiFiBroadcastReceiver”>
    <intent-filter>
    <action android:name=“android.intent.action.WIFI”/>
    </intent-filter>
    </receiver>

Component is still public if android:exported=“false” and It has an intent filter!

Public Interfaces in Android Manifest

Questions Jobs Documentation BETA Tags Users Search...

5

1

I have two similar applications (one free, one paid).

An activity is defined with `exported="false"`

```
<activity
    android:name=".MyActivity"
    android:exported="false"
    android:noHistory="true" >
    <intent-filter>
        <action android:name="android.intent.action.VIEW" />
        <category android:name="android.intent.category.DEFAULT" />
        <data android:mimeType="vnd.android.cursor.item/vnd.mine" />
    </intent-filter>
</activity>
```

When I call `startActivity` with the appropriate implicit intent from the free app, the activity picker appears.

I don't understand why the activity from the paid app appears, since it is `exported="false"`

I suppose I can add an intent filter based on the URL, but my question is: why does the activity from the other app appear when the doc reads

Public Interfaces in Android Manifest

If Your Activity Has an <intent-filter>, Export It

Slightly less than two years ago, I pointed out a problem in Android where an activity that has an `<intent-filter>`, but is marked as not being exported (`android:exported="false"`), screws up the chooser. The chooser ignores the exported flag and offers up the non-exported activity to the user… then promptly crashes if the user actually chooses it.

Dianne Hackborn specifically called this out as being a bug in the app:

> would generally consider this a bug in the app – if you have an activity that you aren't allowing other apps to launch, why the heck are you publishing an intent filter that they will match to try to launch?

What would be nice, of course, is if Google paid attention to its own advice.

The AOSP Music app has five activities that violate this rule:

- `VideoBrowserActivity`
- `ArtistAlbumBrowserActivity`
- `AlbumBrowserActivity`

Prevalence of Public Interfaces

- Examine 872 apps
- 320 of these (37%) have permissions and at least one type of public component
- 9% of all apps perform dynamic permission checks
  - But typically to protect content providers and not services or broadcast receivers
  - Only 1 application in a random set w/ 50 apps does so to protect a service or broadcast receiver
- 11 of 16 system applications are at risk

Implementing the attack

- Constructing the attack
  - Build call graph of the app
  - Search the call graph to find paths from public entry points to protected system APIs
- Likely to miss some viable paths
  - Cannot detect flow through callbacks
- Only construct attacks on API calls for verifiable side effects

[FeltUSENIX11] Felt, Adrienne Porter, et al. "Permission Re-Delegation: Attacks and Defenses." *USENIX Security Symposium*. 2011.

Case Studies

- Build attacks for 5 system apps
  - Settings: phone's primary control panel
    - Settings UI sends intent to Settings receiver on user's button clicks
    - Unprivileged app can also send intents to this broadcast receiver
    - Requires CHANGE_WIFI_STATE, BLUETOOTH_ADMIN, ACCESS_FINE_LOCATION permissions
  - DeskClock: time and alarm functionality
    - Public service that accepts directions to play alarms
    - Send intent to indefinitely vibrate the phone (prevent phone from sleeping)
    - Requires VIBRATE and WAKE_LOCK permissions

[FeltUSENIX11] Felt, Adrienne Porter, et al. "Permission Re-Delegation: Attacks and Defenses." *USENIX Security Symposium*. 2011.

Defense

- Ideas borrowed from:
  - Stack inspection
    - When a privileged API call is made, system checks within a runtime whether the call stack includes any unprivileged application. Dependent on runtime.
  - History-based access control (HBAC)
    - Reduces the permissions of trusted code after interactions with untrusted code. Relies on runtime mechanisms.
  - Mandatory access control (MAC)
    - Central flow control by OS enforced fixed info. flow policy
    - Apps cannot be strictly ordered in terms of integrity level

We need runtime independence and ability of reduction of privileges!

[FeltUSENIX11] Felt, Adrienne Porter, et al. "Permission Re-Delegation: Attacks and Defenses." *USENIX Security Symposium*. 2011.

IPC Inspection

- When an app receives a message from another app, reduce the privileges of recipient to the intersection of recipient’s and requester’s permissions
  - Implemented in the OS, not in the runtime.
  - Maintain a list of current permissions for each app
  - Build privilege reduction into system’s IPC mechanism
  - Allow apps to accept or reject messages
    - They can register a set of acceptable requesters
    - Requesters can be identified individually (domain) or based on their permissions

[FeltUSENIX11] Felt, Adrienne Porter, et al. "Permission Re-Delegation: Attacks and Defenses." *USENIX Security Symposium*. 2011.

IPC Inspection Implementation

- There can be multiple requesters
  - Create new app instances for the deputy if privilege reduction is necessary
  - Instance reuse
    - Primary instance can be reused in an install-time system
    - Not possible with time-of-use systems since deputy could dynamically request permissions and it isn't clear which requester is responsible for the permission prompt
- Singleton deputy apps will have their permissions repeatedly reduced until app exists

Attacks on Android

- Privilege Escalation Attacks on Android
- Web Attacks on Android

Embedded Web Browsers

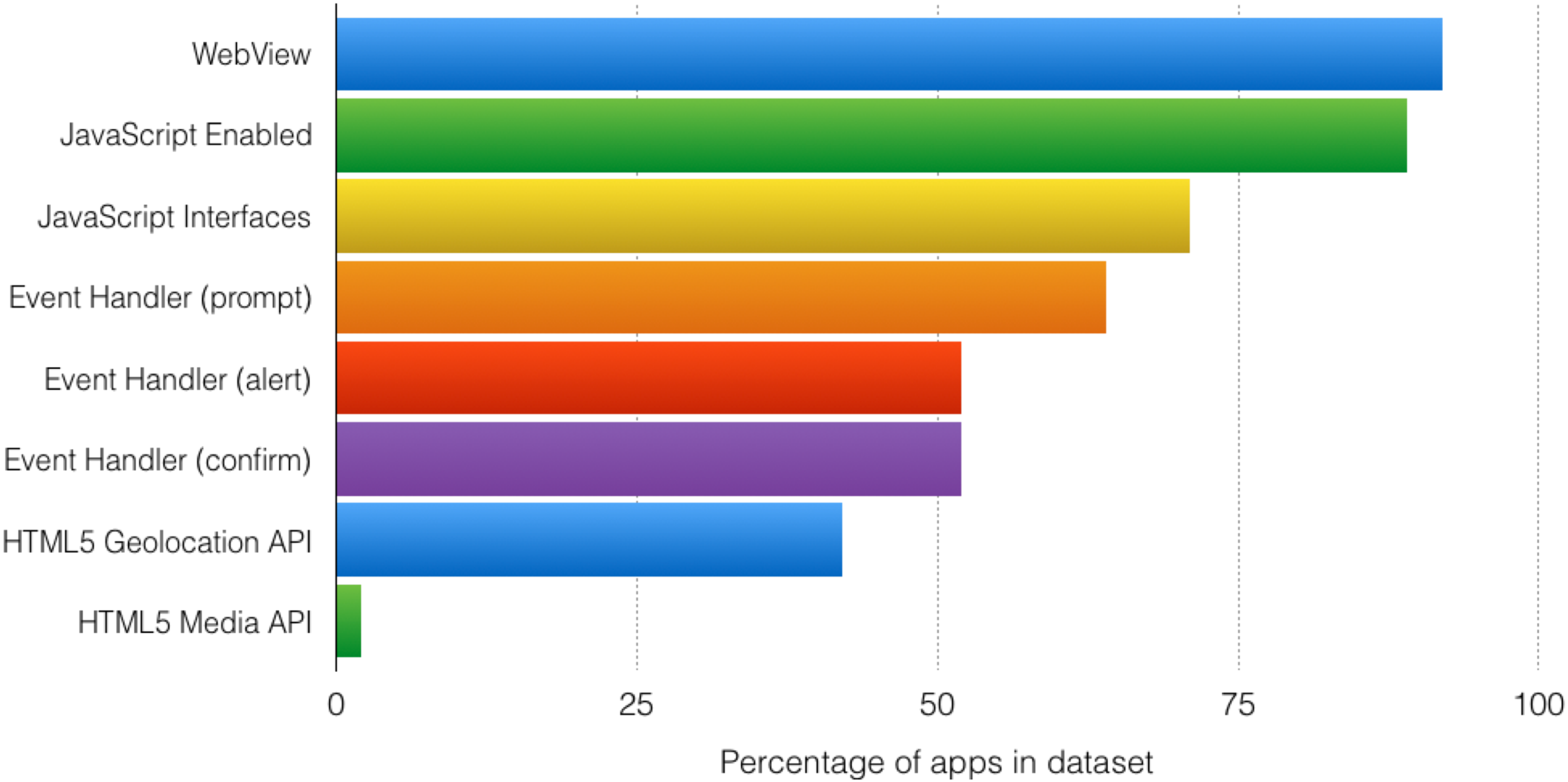
- Web container for showing web pages within app context
- >90% of apps in Google Play Store use WebView
- Interesting use cases:
  - Displaying ads
  - Reuse of web code
  - Hybrid frameworks

WebView API

- Web settings
  - setJavaScriptEnabled()
  - setAllowFileAccess()
- Navigation
  - shouldOverrideUrlLoading()
- App code access
  - JavaScript interfaces
  - JavaScript event handlers
    - onJsAlert(), onJsPrompt(), onJsConfirm()
- HTML5 API
  - GeoLocation, getUserMedia
  - App should have permissions
- Loading content
  - loadUrl() etc.
  - "http://", "https://", "file://", "javascript:"

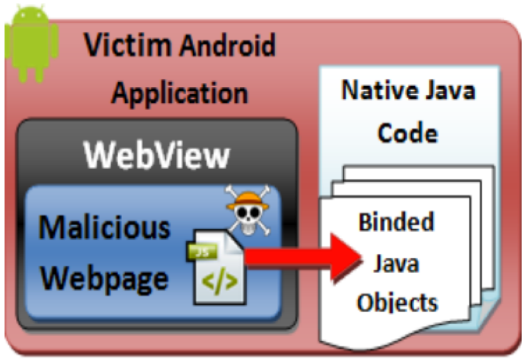
```java
mWebView.addJavaScriptInterface(new MyJSInterface(),
    "InjectedObject");
//...
public class MyJSInterface {
  @JavaScriptInterface
  public void myExposedMethod() {
    // do some sensitive activity
  }
  public void myHiddenMethod() {
    // JavaScript cannot access me, do some other activity
  }
}
```

Prevalence of WebView API

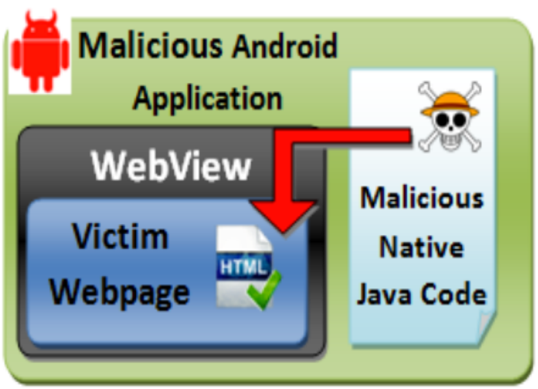


Web Attacks on Android

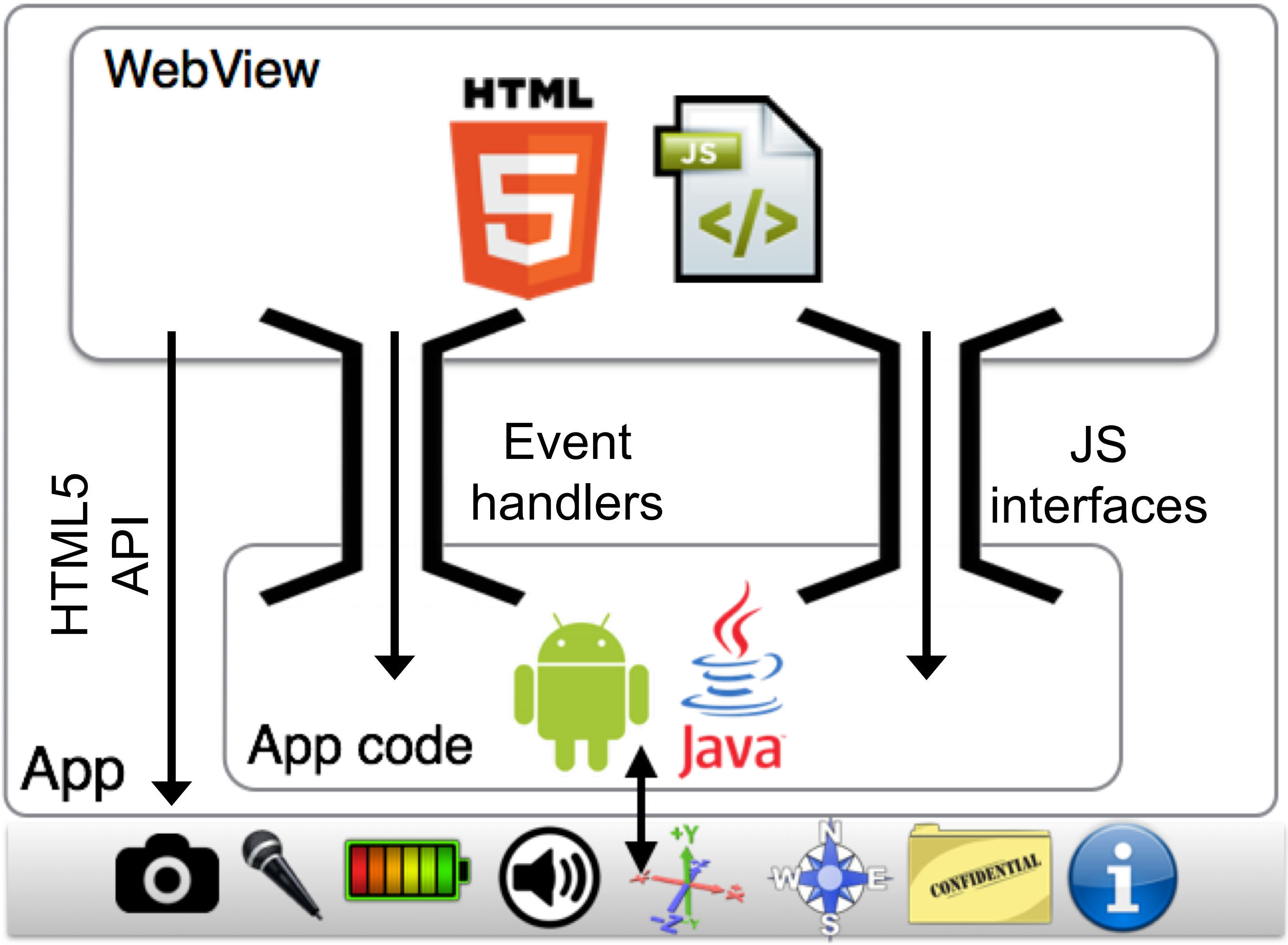
- Web to app attacks
  - Excess authorization
    - Web domains abuse app/device resources
  - File-based cross-zone scripting
    - loadUrl(“file://….html”)
    - File system access by third party domains



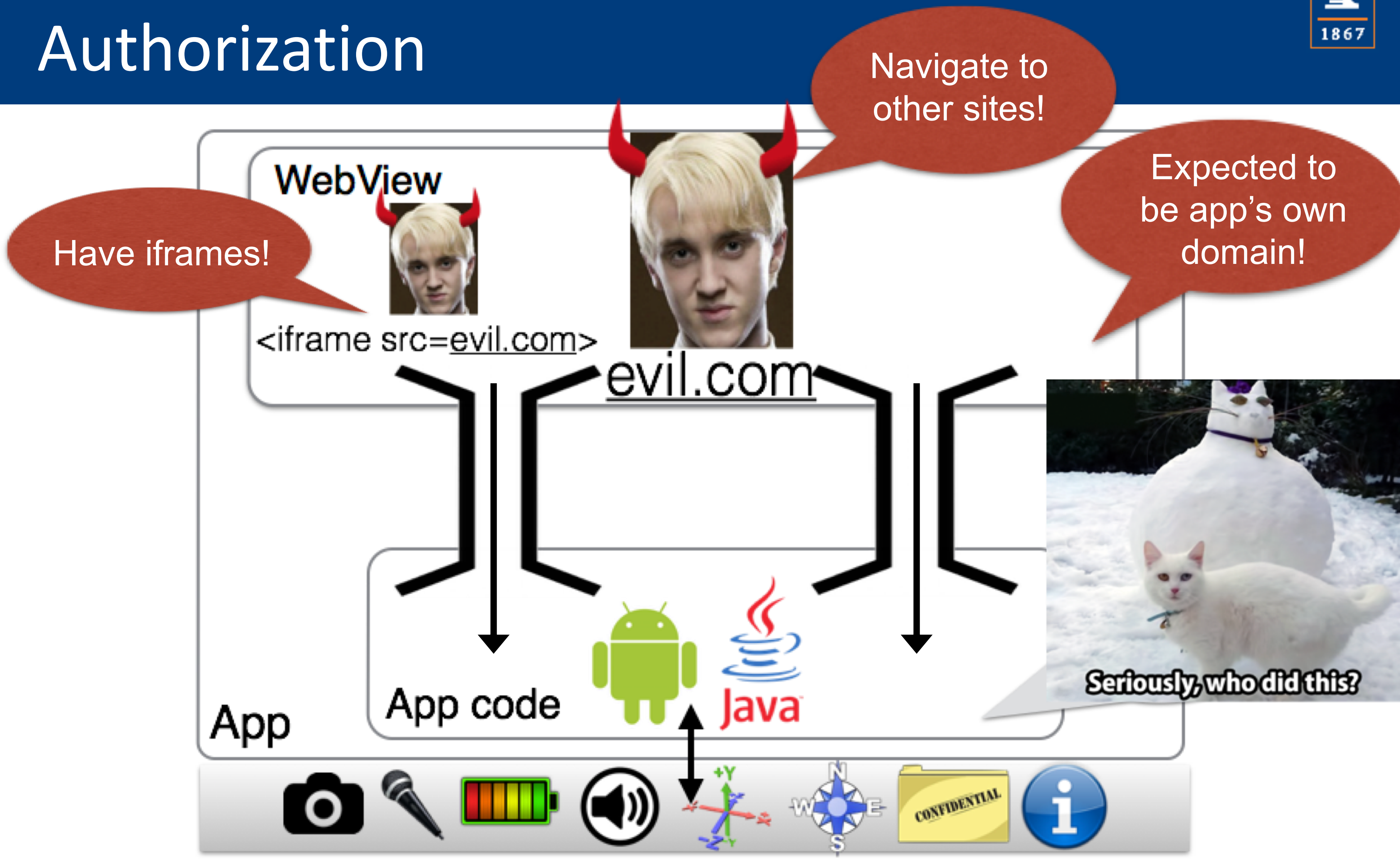
- App to web attacks
  - JavaScript injection
    - loadUrl(“javascript:….”)
  - Event sniffing and hijacking
    - doUpdateVisitedHistory, onFormResubmission



App-Web Code Interaction

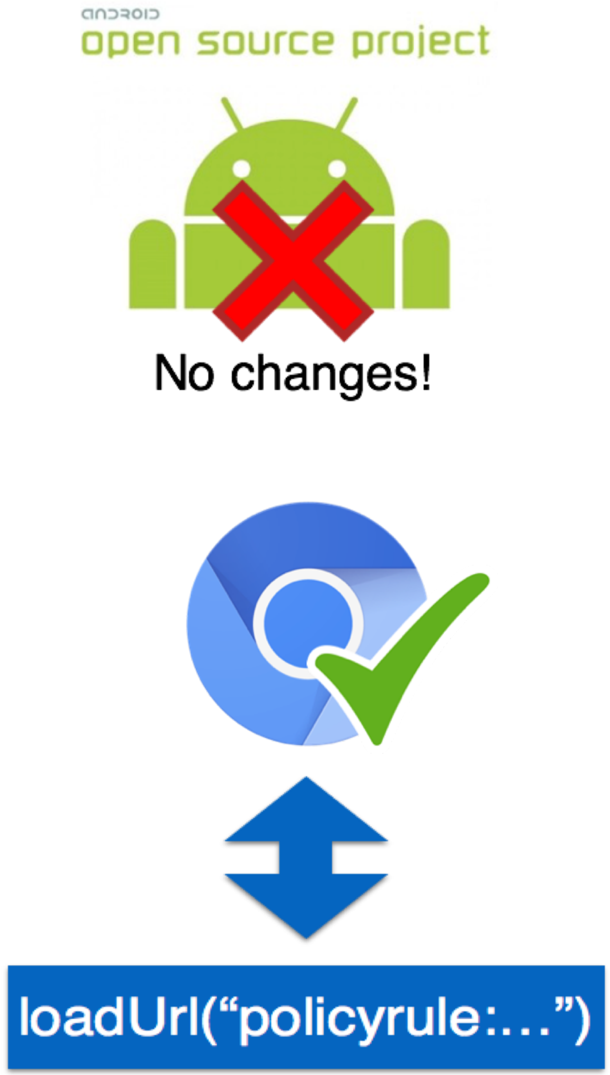


Threat Model for Excess Authorization



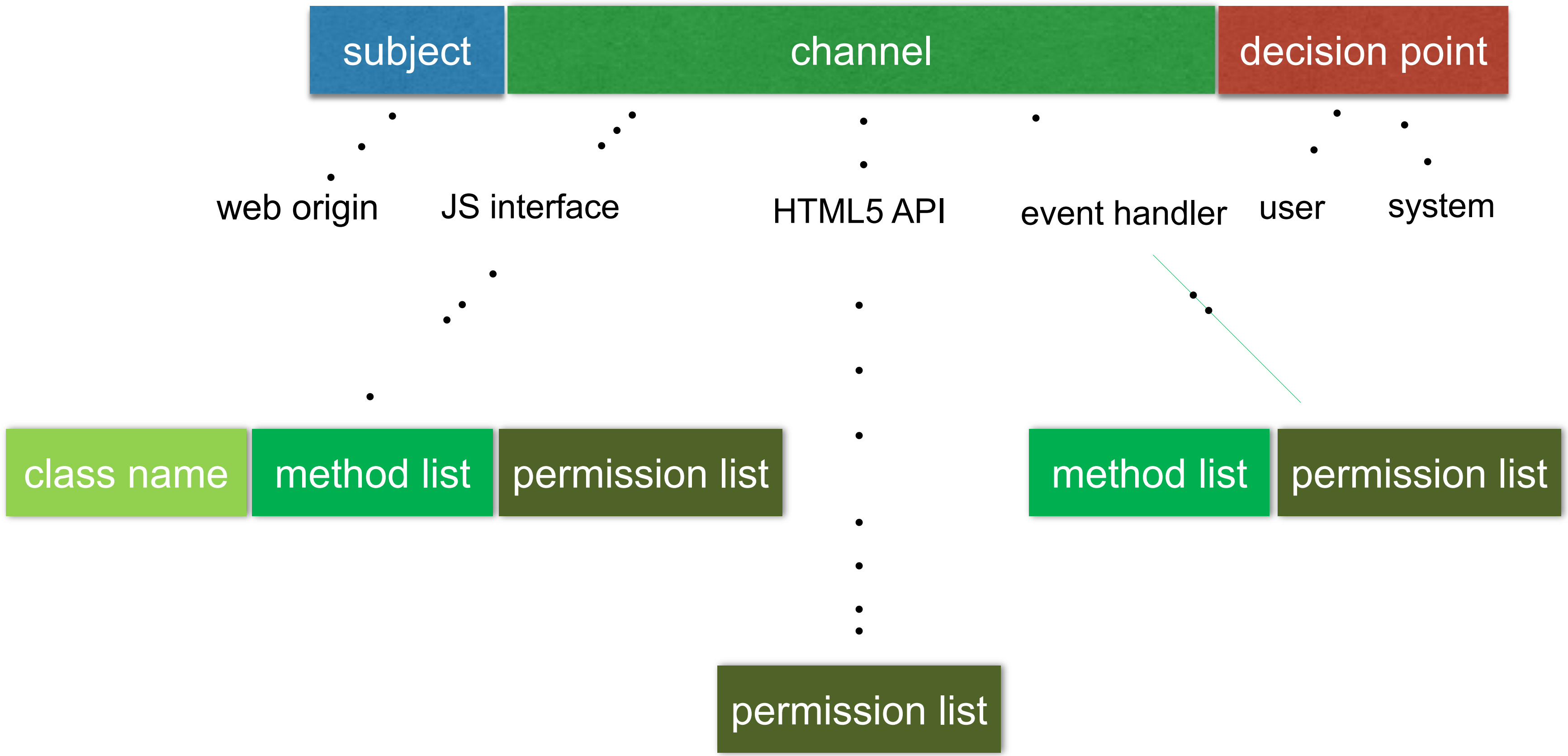
Defense: Draco

- Fine grained and origin based access control for WebView
- Protect *all* parts of *all* three access channels for *all* types of apps uniformly
- 2 main components
  – Draconian Policy Language
  – Draco Runtime System



[TuncayCCS2016] Tuncay, Guliz Seray et al. "Draco: A System for Uniform and Fine-grained Access Control for Web Code on Android. CCS 2016"

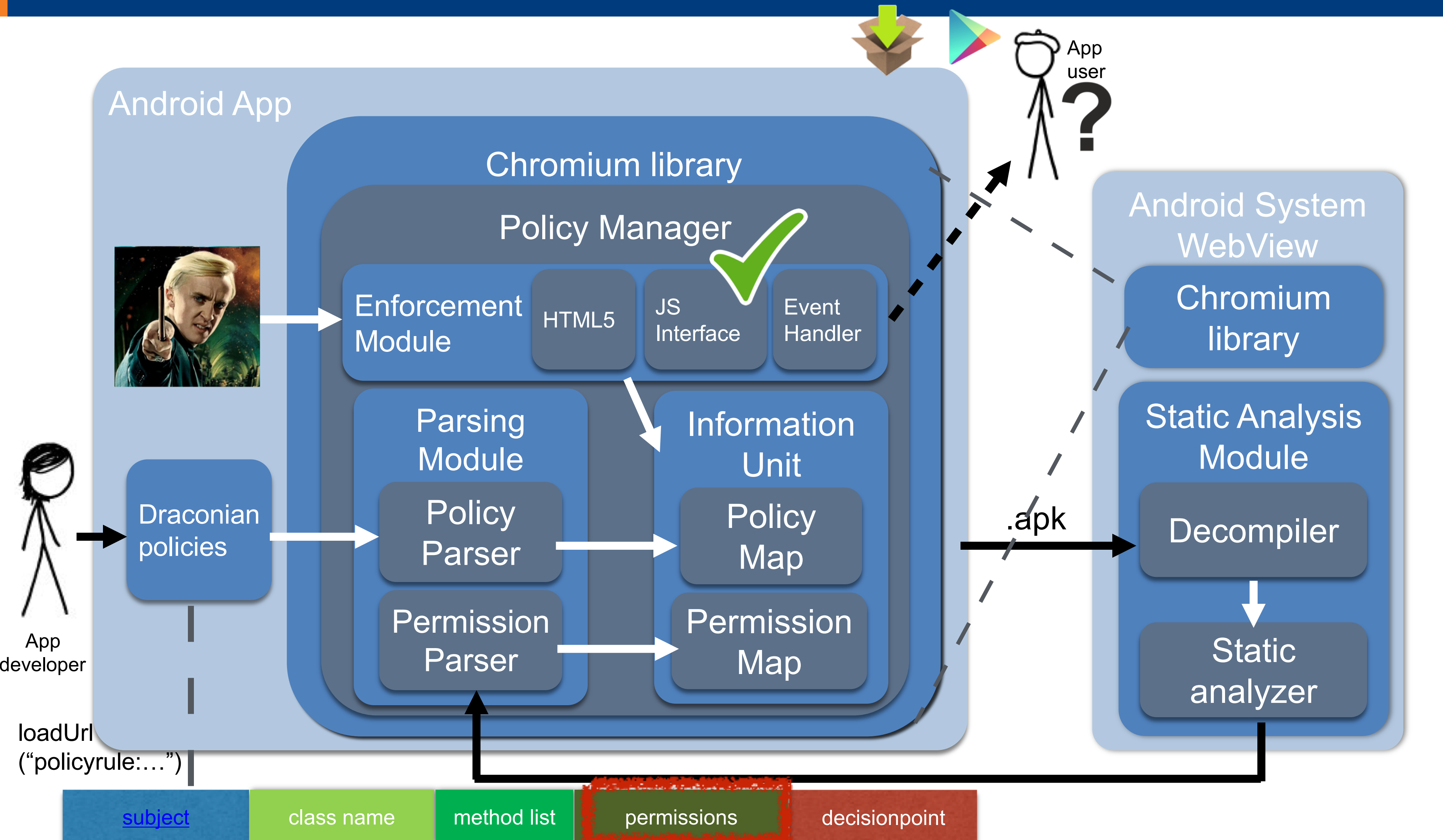
Draconian Policy Language



Policy rule example:

https://www.caremark.com | WebViewJavascriptInterface | <all> | geolocation, camera | decisionpoint<system>

Draco Architecture



Mobile & Device Security: Looking Forward

- Where to look for literature: “Big 4” security conferences (IEEE S&P a.k.a. Oakland, USENIX Security, CCS, NDSS), WiSec, SPSM workshop (now merged with WiSec), MobiSys
- Hot topics in mobile & device security (not exhaustive):
  – Android permissions
  – Mobile advertising & third-party libraries
  – Side-channel attacks on mobile devices
  – IoT security