# ICC Leak and Taint Analysis for Android App

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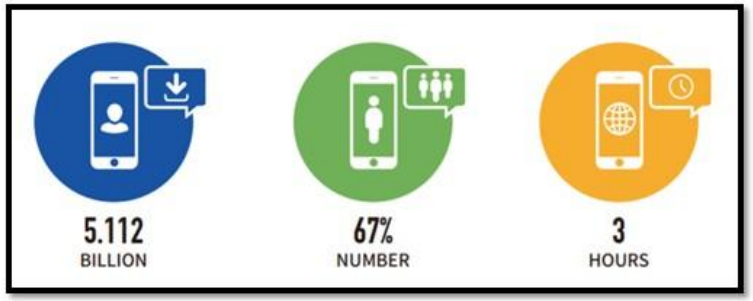
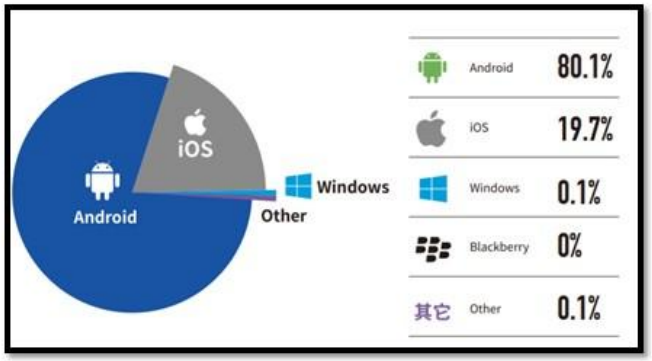
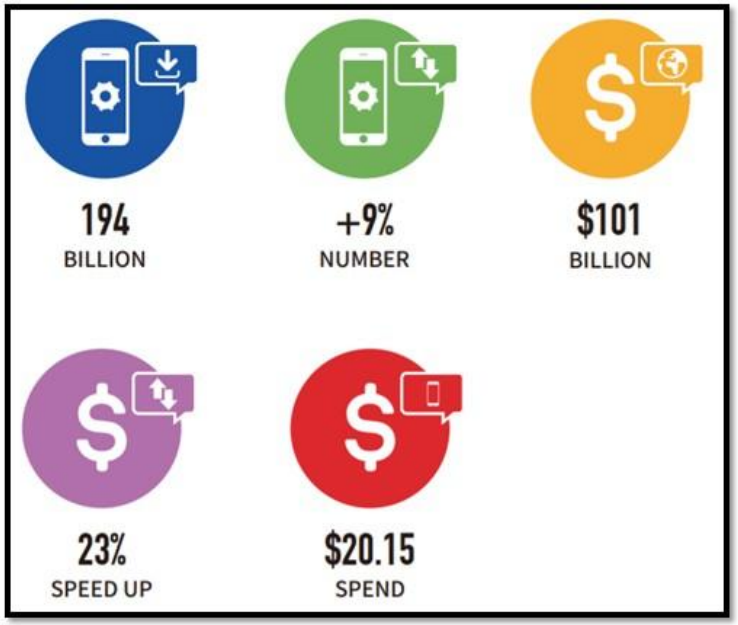
# Android Development



# Android App and Market

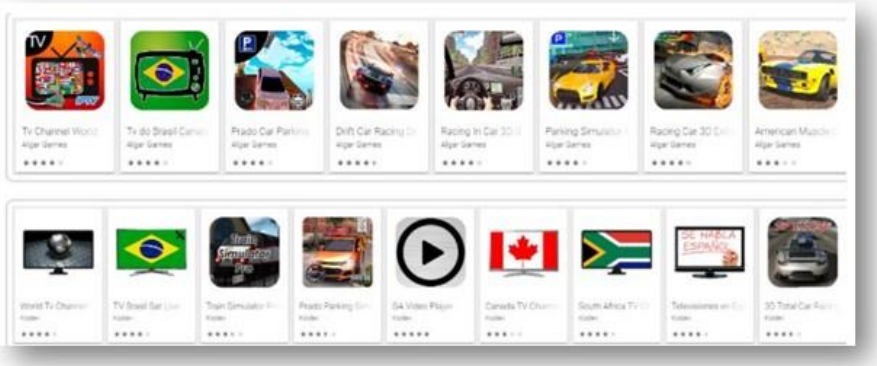


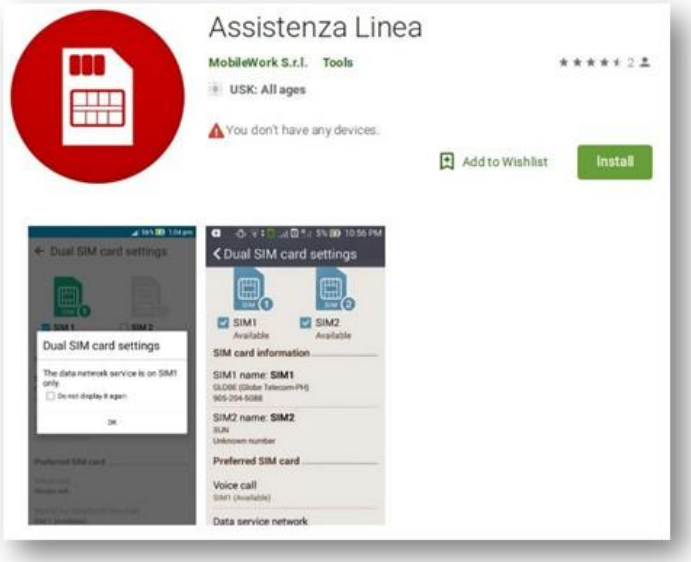
# Security Events


图：央视曝光恶意的免费充电桩

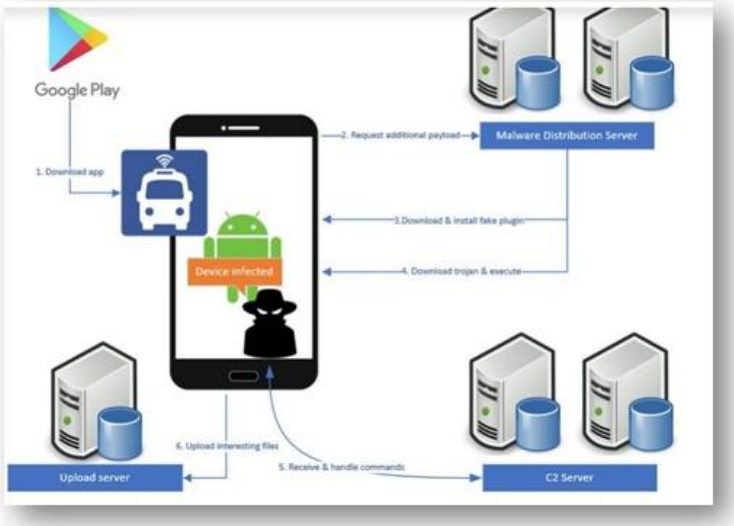


图：GooglePlay上一些广告软件虚假应用截图

# Security Events

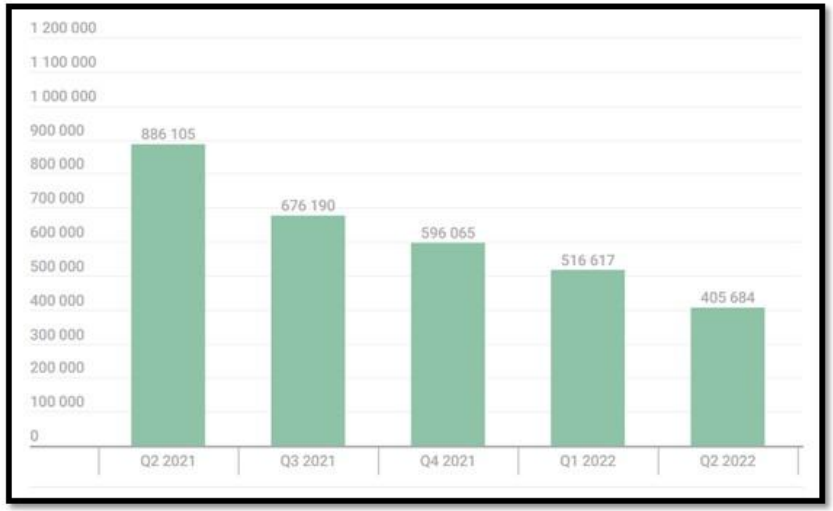


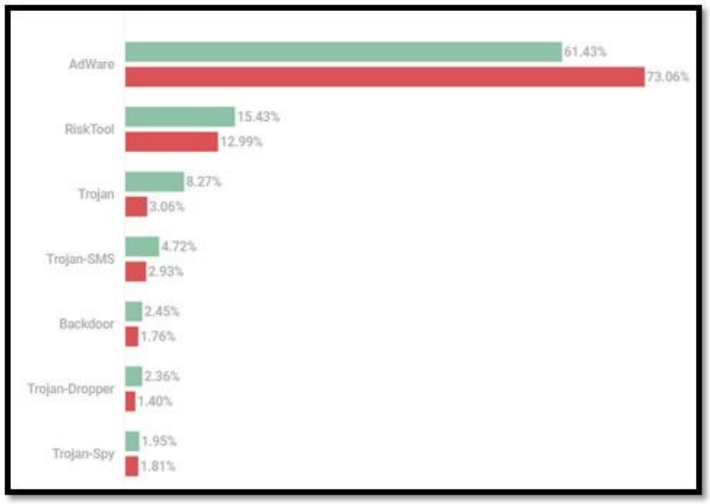

图：Exodus在Google Play中的下载页面




图：韩国公交车App感染流程

# Security Risk within Android



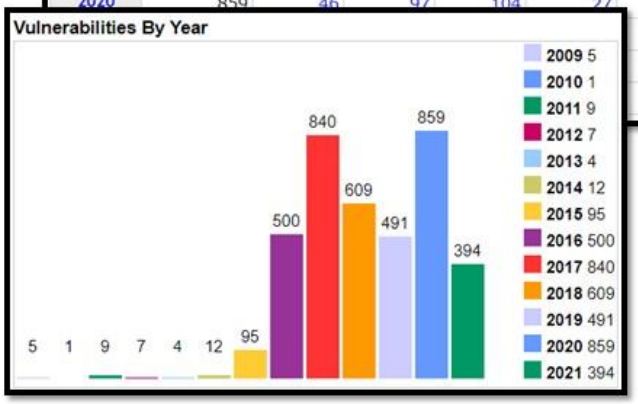



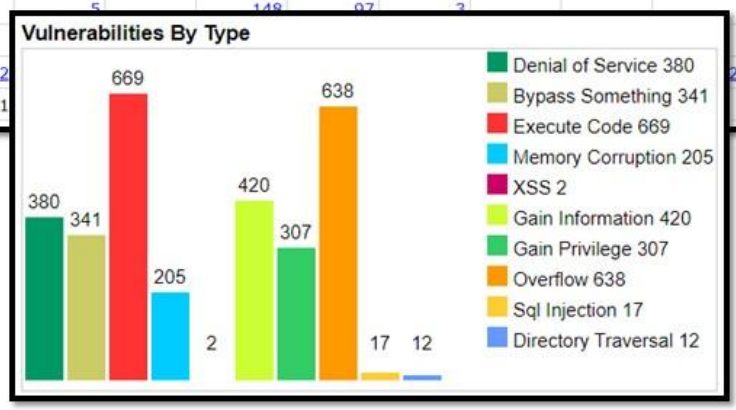
# Cost of Security Android

- 1. Malware attacks cost the average US business well over $2 million.
- 2. Five-year forecasts for malware security are set to be in the $1 trillion ballpark.
- 3. A malware attack can cost 50 days in time to defense.
- 4. Malware costs have risen by over 20% per year.
- ……
- 11. Yahoo had 3 billion accounts compromised
- 12. Reports show that 37.5 million records were stolen in one of the largest malware heists in history.

## Vulnerability Trends Over Time

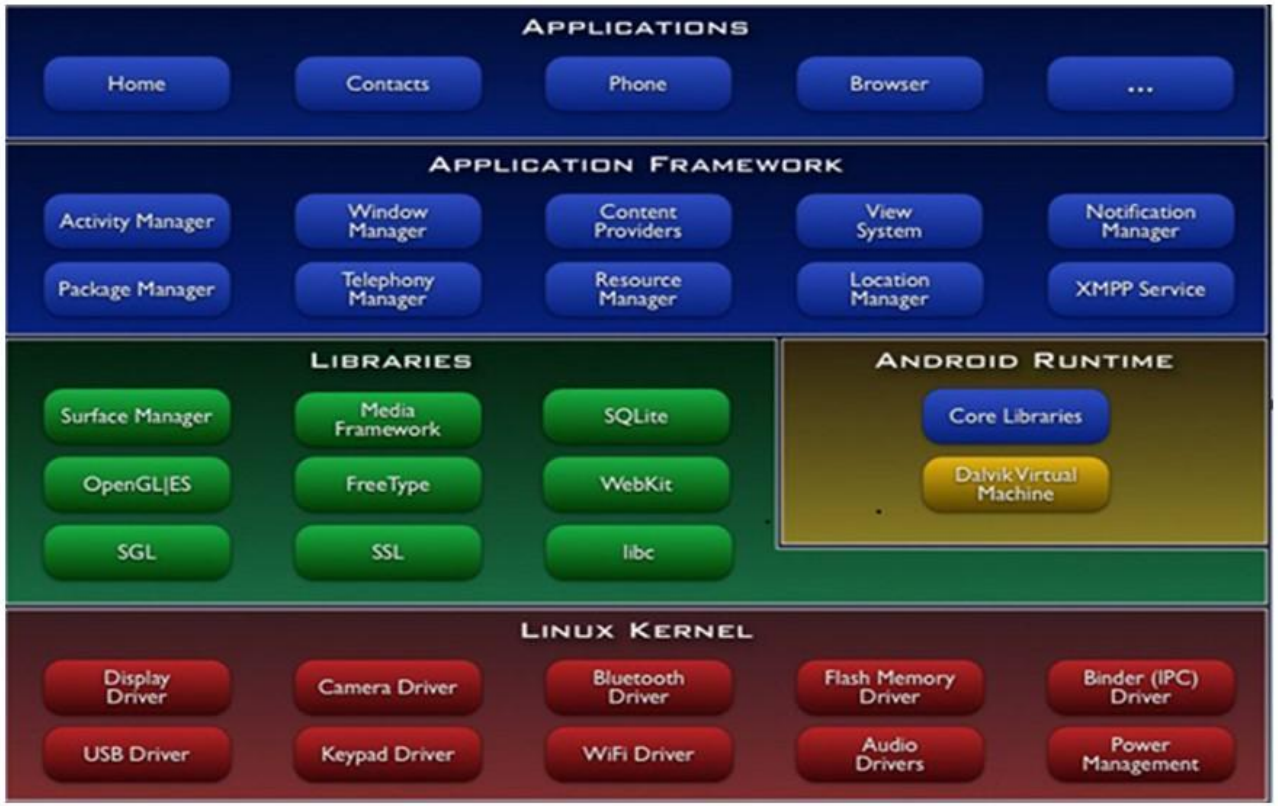
| Year | # of Vulnerabilities | DoS | Code Execution | Overflow | Memory Corruption | Sql Injection | XSS | Directory Traversal | Http Response Splitting | Bypass something | Gain Information | Gain Privileges | CSRF | File Inclusion | # of exploits |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | 5 | 3 | | | | | | | | 1 | | | | | |
| 2010 | 1 | 1 | 1 | | | | | | | | | | | | |
| 2011 | 9 | 1 | 1 | | 1 | | 1 | | | 4 | 1 | 3 | | | |
| 2012 | 7 | 5 | 3 | 2 | | | | | | | 1 | | | | 1 |
| 2013 | 4 | | 1 | 1 | 1 | | | | | 1 | 1 | 1 | | | |
| 2014 | 12 | 2 | 4 | 1 | | 1 | | | | 1 | 2 | 1 | | | 1 |
| 2015 | 95 | 46 | 49 | 50 | 37 | | | | | 13 | 14 | 17 | | | |
| 2016 | 500 | 104 | 72 | 91 | 38 | | | | | 47 | 96 | 236 | | | |
| 2017 | 840 | 86 | 206 | 170 | 32 | | | 1 | | 30 | 113 | 36 | | | |
| 2018 | 609 | 32 | 84 | 143 | 12 | 2 | 1 | 2 | | 17 | 63 | 3 | | | |
| 2019 | 491 | 37 | 107 | 41 | 24 | 3 | | 1 | | 39 | 22 | 1 | | | |
| 2020 | 859 | 46 | 97 | 104 | 27 | 9 | | 5 | | 148 | 97 | 3 | | | |
| | | | | | | 2 | | | | | | | | | |
| | | | | | | 17 | 2 | | | | | | | | 2 |
| | | | | | | 0.4 | 0.1 | | | | | | | | |



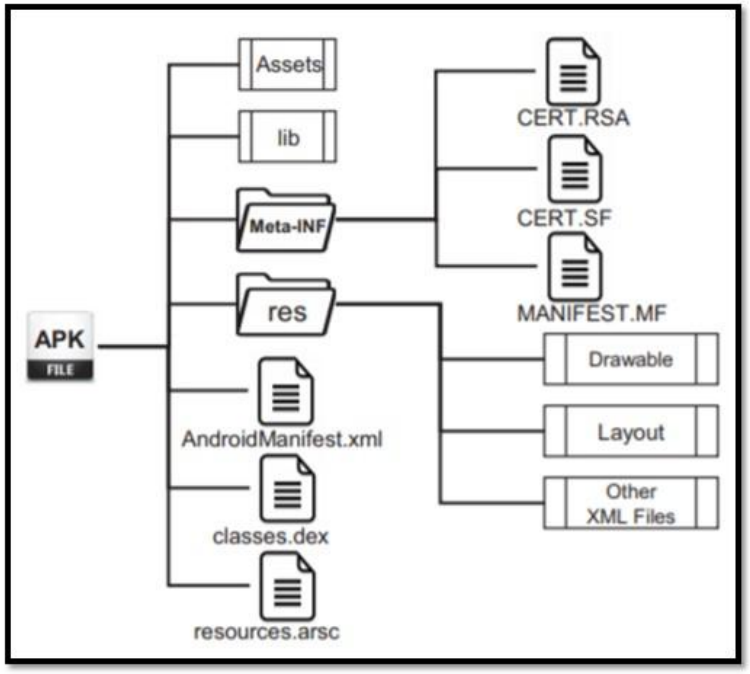



# Android Structure

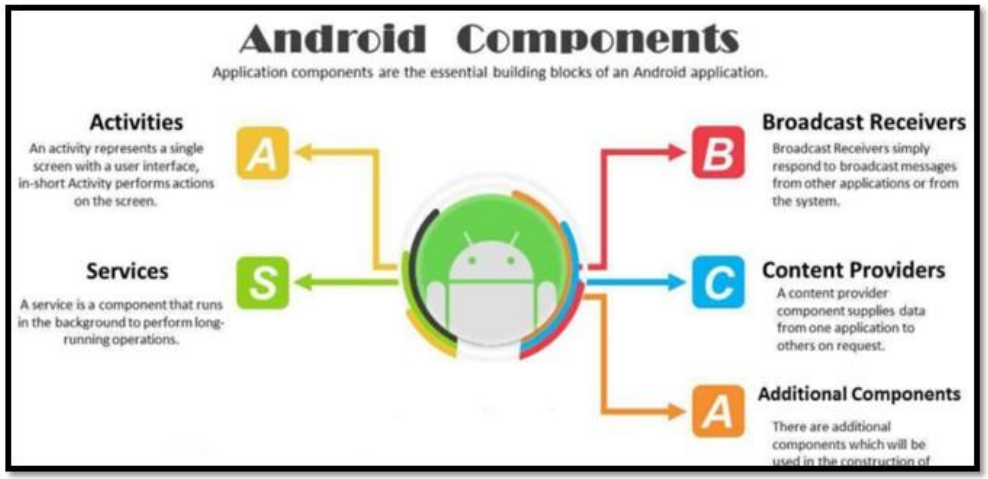
android.app -
android.content -
android.database
android.opengl
android.os -
android.text -
android.view -
android.widget -
android.webkit

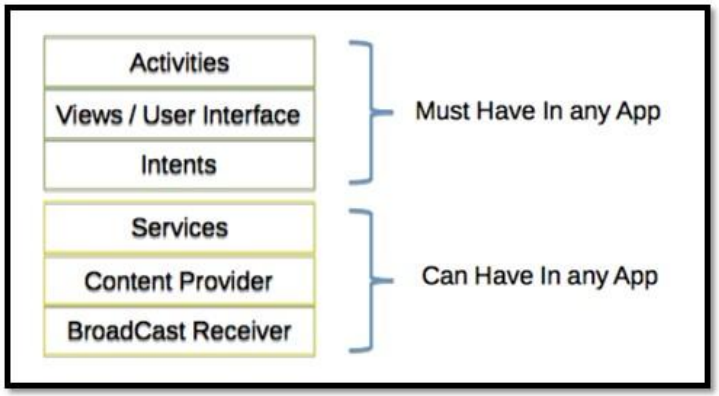


# App File Structure

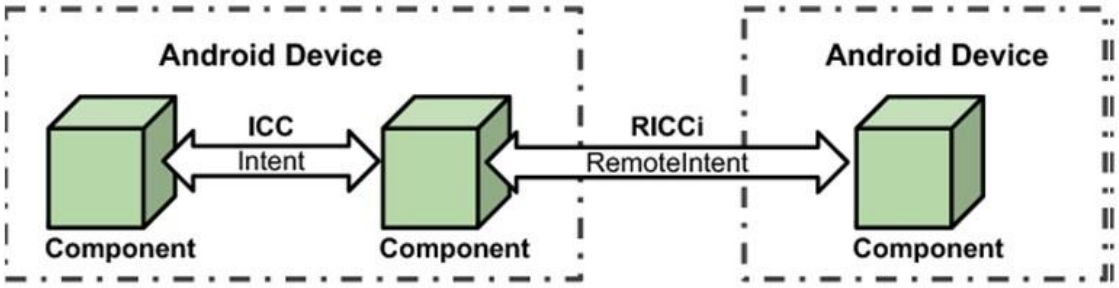


# Component


Android Components
Application components are the essential building blocks of an Android application.
Activities
An activity represents a single screen with a user interface, in-short Activity performs actions on the screen.
Services
A service is a component that runs in the background to perform long-running operations.
Broadcast Receivers
Broadcast Receivers simply respond to broadcast messages from other applications or from the system.
Content Providers
A content provider component supplies data from one application to others on request.
Additional Components
There are additional components which will be


Activities
Views / User Interface
Intents
Must Have In any App
Services
Content Provider
BroadCast Receiver
Can Have In any App

# Inter-component Communication (ICC)



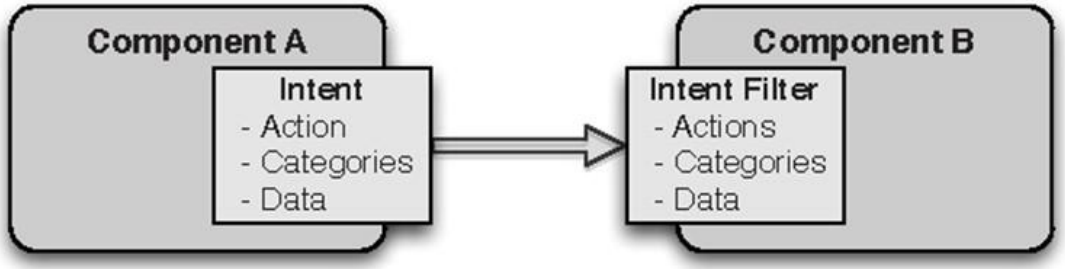
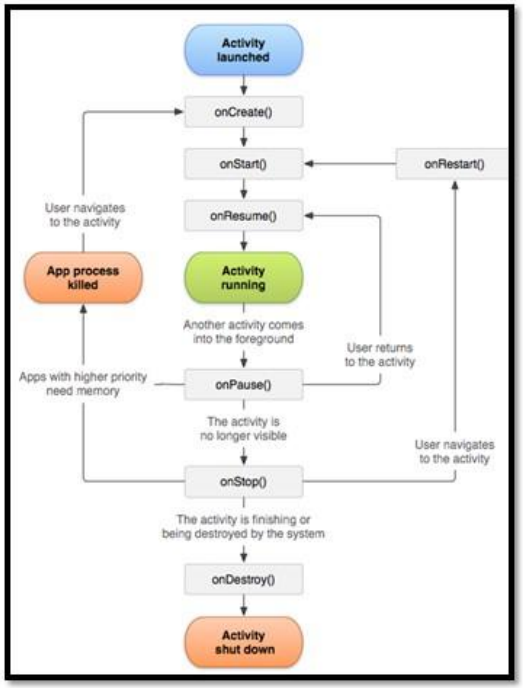
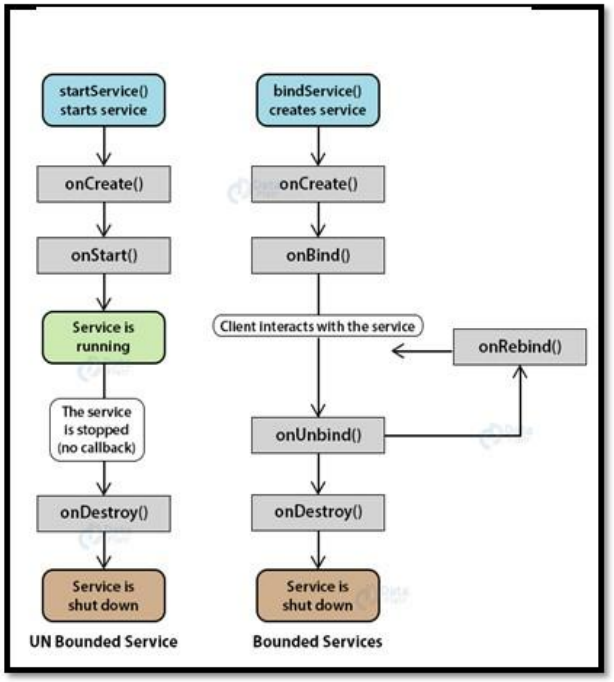



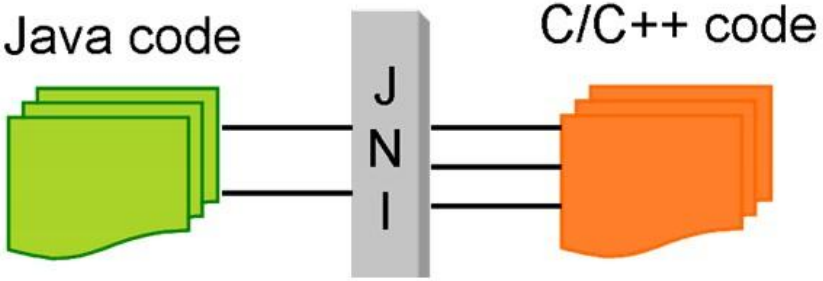

Figure 1: Implicit Intent ICC

# Android Lifecycle



# Java Native Interface (JNI)




Why?

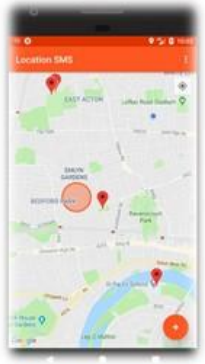
Safe & Efficiency

# Permission

Totally 324

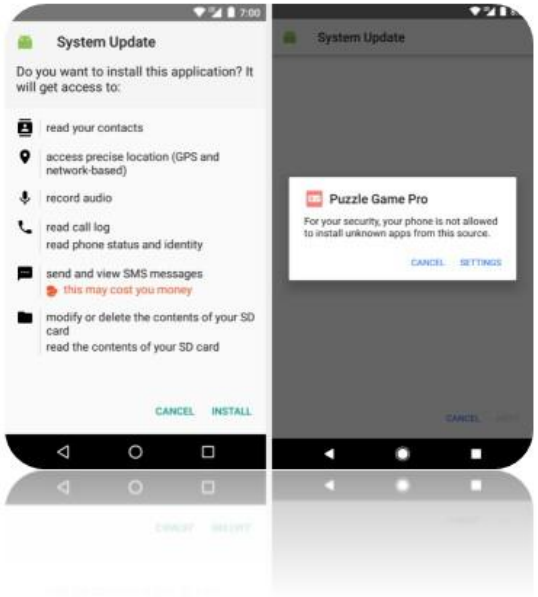
```
1   android.permission.ACCESS_ALL_DOWNLOADS
2   android.permission.ACCESS_BLUETOOTH_SHARE
3   android.permission.ACCESS_CACHE_FILESYSTEM
4   android.permission.ACCESS_CHECKIN_PROPERTIES
5   android.permission.ACCESS_CONTENT_PROVIDERS_EXTERNALLY
6   android.permission.ACCESS_DOWNLOAD_MANAGER
7   android.permission.ACCESS_DOWNLOAD_MANAGER_ADVANCED
8   android.permission.ACCESS_DRM_CERTIFICATES
9   android.permission.ACCESS_EPHEMERAL_APPS
10  android.permission.ACCESS_FM_RADIO
11  android.permission.ACCESS_INPUT_FLINGER
12  android.permission.ACCESS_KEYGUARD_SECURE_STORAGE
13  android.permission.ACCESS_LOCATION_EXTRA_COMMANDS
14  android.permission.ACCESS_MOCK_LOCATION
15  android.permission.ACCESS_MTP
16  android.permission.ACCESS_NETWORK_CONDITIONS
17  android.permission.ACCESS_NETWORK_STATE
18  android.permission.ACCESS_NOTIFICATIONS
19  android.permission.ACCESS_NOTIFICATION_POLICY
20  android.permission.ACCESS_PDB_STATE
21  android.permission.ACCESS_SURFACE_FLINGER
22  android.permission.ACCESS_VOICE_INTERACTION_SERVICE
23  android.permission.ACCESS_VR_MANAGER
24  android.permission.ACCESS_WIFI_STATE
```

Apply for

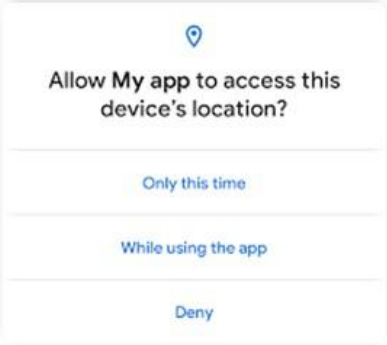




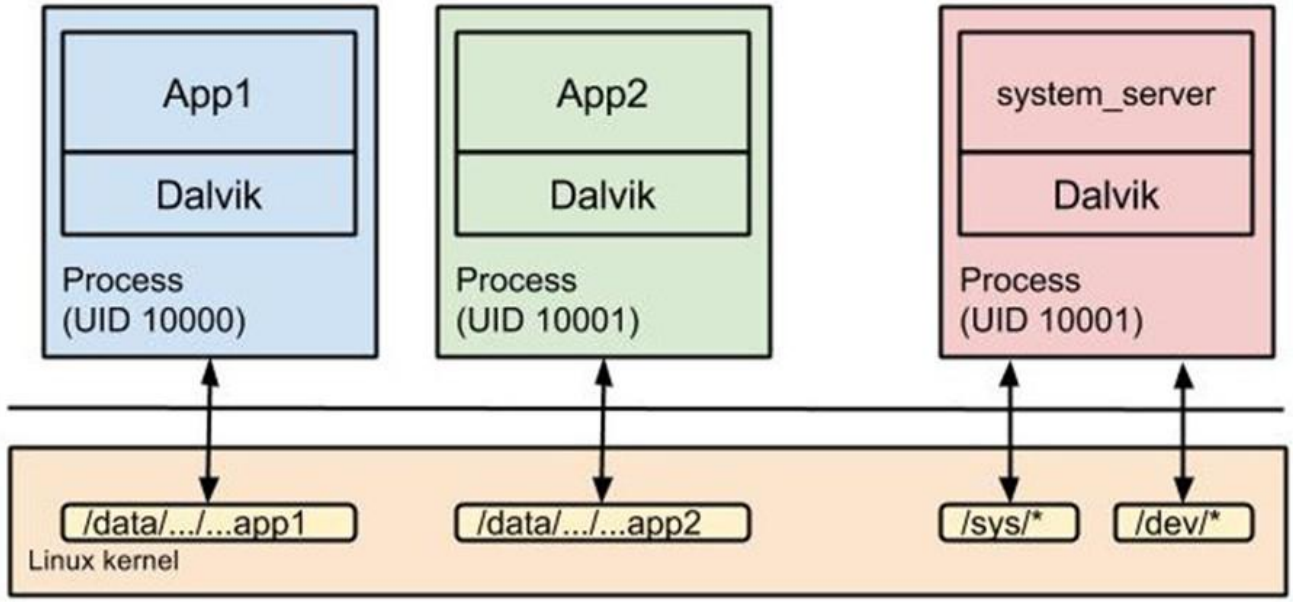
# Permission


System Update
Do you want to install this application? It will get access to:
read your contacts
access precise location (GPS and network-based)
record audio
read call log
read phone status and identity
send and view SMS messages
this may cost you money
modify or delete the contents of your SD card
read the contents of your SD card
CANCEL
INSTALL
System Update
Puzzle Game Pro
For your security, your phone is not allowed to install unknown apps from this source.
CANCEL
SETTINGS


Allow Hangouts to send and view SMS messages?
DENY
ALLOW


Allow My app to access this device's location?
Only this time
While using the app
Deny

# Android SandBoxing



# Security Problem in Android App

- Leaks (inner-component, ICC, SD card…)
- Vulnerability (DoS, Arbitrary execution, Buffer overflow…)
- Permission exploitation (Privilege escalation)
- Malware
- Repackaging
- Cryptography

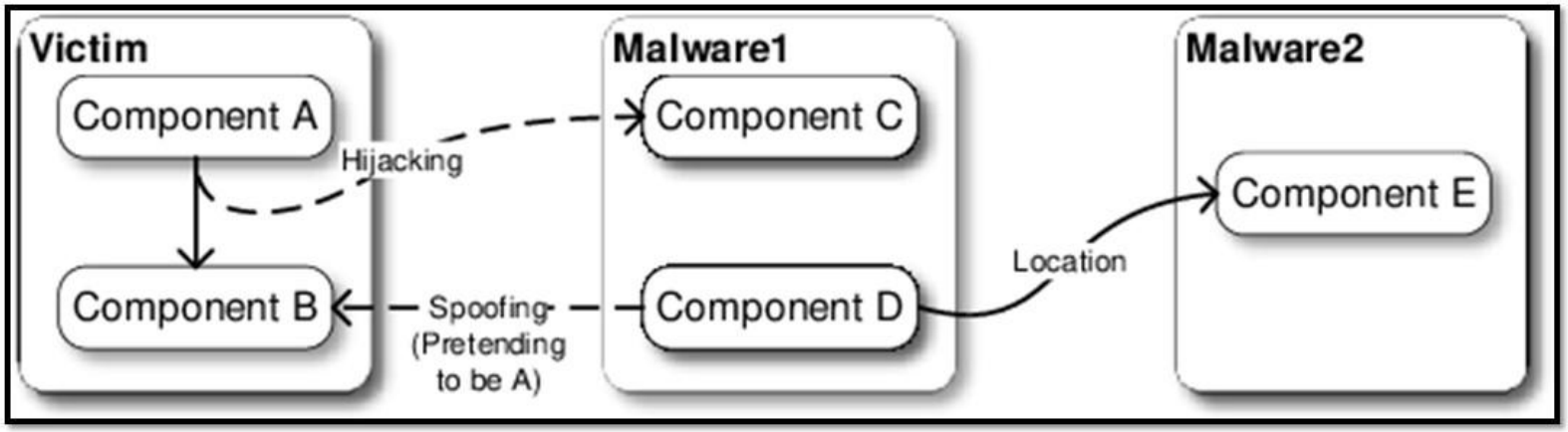
# A Case for Permission


App icon of a legitimate app is clicked by the victim.

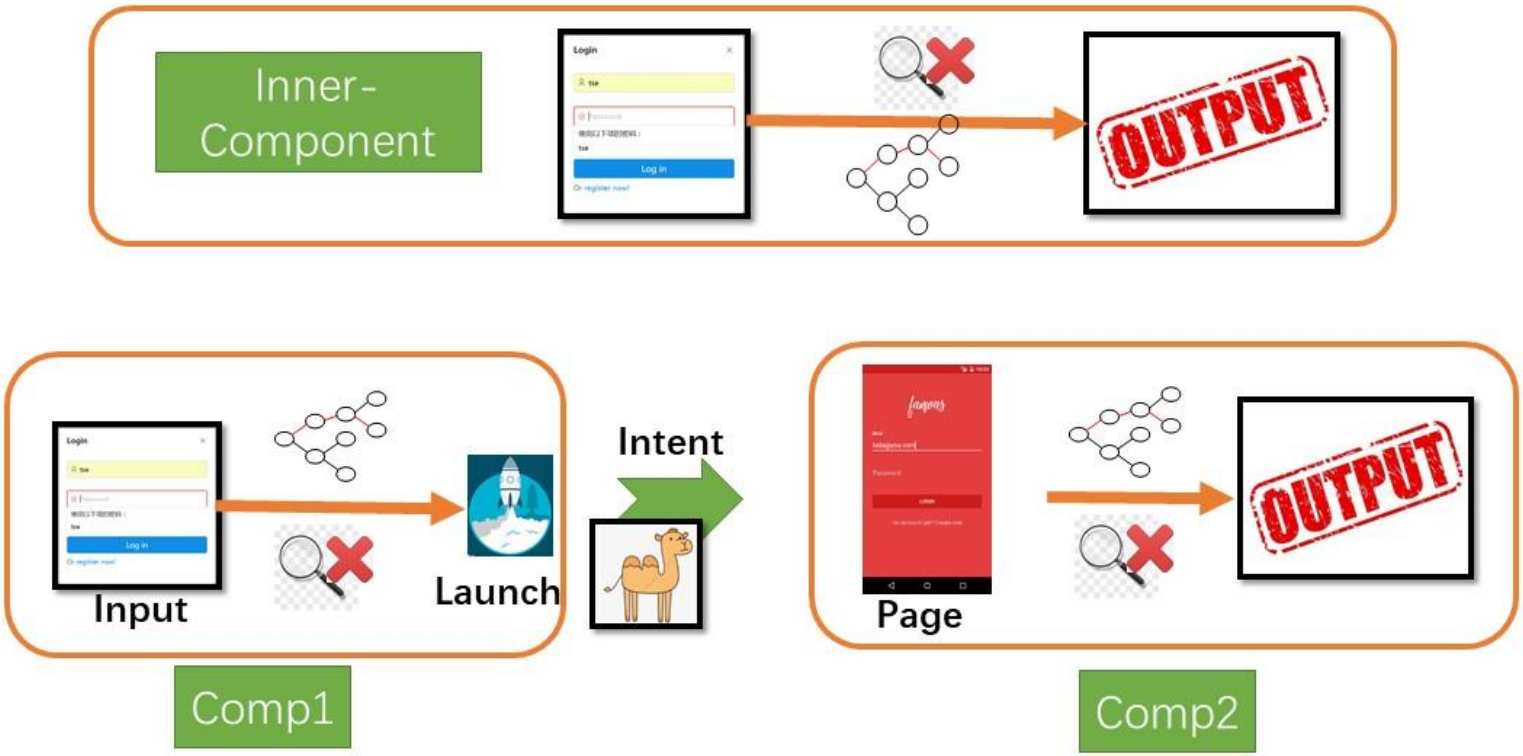
Instead of seeing the legitimate app, the malware is displayed and can now ask for any permission while pretending to be the legitimate app.

The victim is unknowingly giving permissions to the hacker. Victim is directed to the legitimate app.

# ICC-based Attack



# ICC-based Leakage

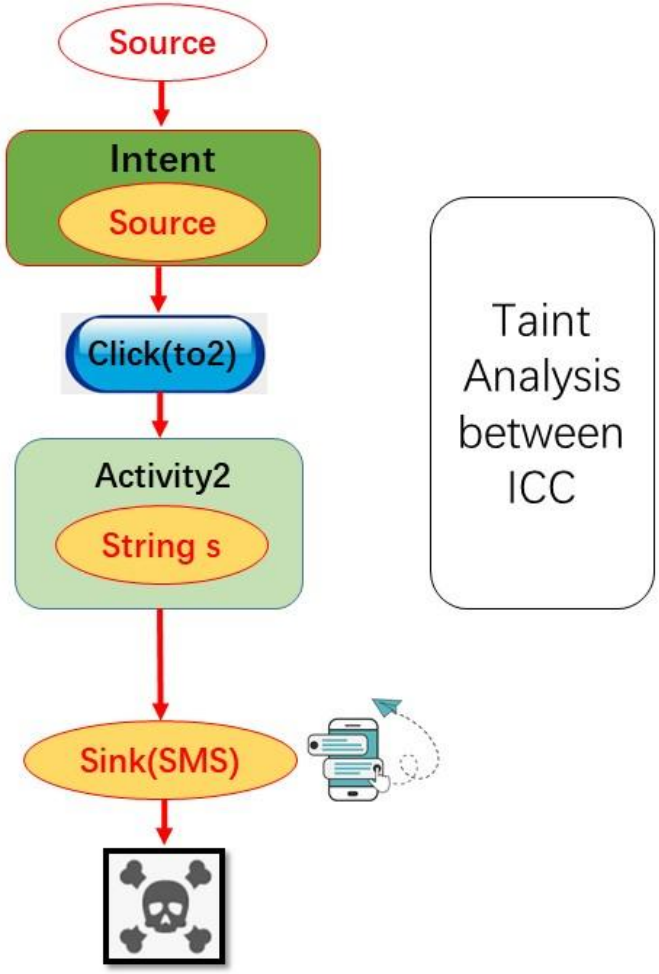


# ICC-based Leakage

```
1  //TelephonyManager telMnger; (default)
2  //SmsManager sms; (default)
3  class Activity1 extends Activity {
4   void onCreate(Bundle state) {
5    Button to2 = (Button) findViewById(to2a);
6    to2.setOnClickListener(new OnClickListener(){
7     void onClick(View v) {
8      String id = telMnger.getDeviceId();
9      Intent i = new
        Intent(Activity1.this,Activity2.class);
10     i.putExtra("sensitive", id);
11     Activity1.this.startActivity(i);
12 }});}}
13 class Activity2 extends Activity {
14  void onStart() {
15   Intent i = getIntent();
16   String s = i.getStringExtra("sensitive");
17   sms.sendTextMessage(number,null,s,null,null);
18 }}
```

Source

Sink




Taint Analysis between ICC

# Detection ICC-based Leakage

Apparecium [1], AppAudit [2], AppCaulk [3], AppIntent [4], Apposcopy [5], AppSealer [6], AsDroid [7], Bastani et al. [8], Bonett et al. [9], Brox [10], Capper [11], Cortesi et al. [12], DescribeMe [13], Dflow + DroidInfer [14], DroidJust [15], DynaLog [16], **FlowDroid [17],** Graa et al. [18], HelDroid [19], HornDroid [20], **IccTA [21],** IFT [22], Jiang et al. [23], Octeau et al. [24], Relda [25], Sufatrio et al. [26], TASMAN [27], Tuan et al. [28], Uranine [29], WeChecker [30], ATFuzzer [31], Chen et al. [32], ContentScope [33], DroidAlarm [34], **DroidSafe [35],** DroidUnPACK [36], DroidVulMon [37], Schoepe et al. [38], Tiwari [39], **AmanDroid[40], Epicc[41], RAICC[42],** CHEX[43], Didfail[44], ArrayICC[45]

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# SuSi

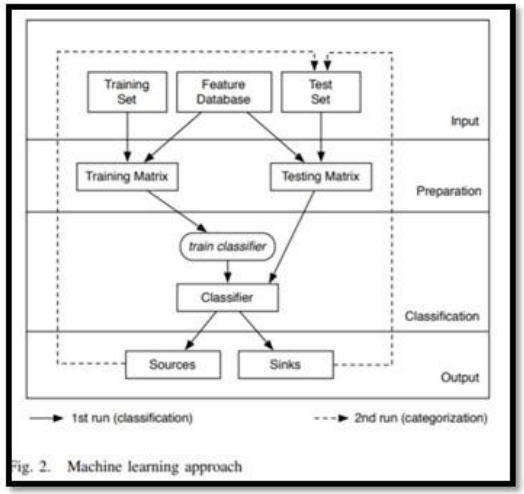


Fig. 2. Machine learning approach

SVM Classifier

| Category | Recall [%] | Precision [%] |
|---|---|---|
| ACCOUNT | 100.0 | 100.0 |
| BLUETOOTH | 83.3 | 100.0 |
| BROWSER | 83.0 | 100.0 |
| CALENDAR | 100.0 | 100.0 |
| CONTACT | 95.0 | 100.0 |
| DATABASE | 50.0 | 100.0 |
| FILE | 75.0 | 100.0 |
| NETWORK | 83.3 | 83.3 |
| NFC | 100.0 | 100.0 |
| SETTINGS | 75.0 | 85.7 |
| SYNC | 100.0 | 100.0 |
| UNIQUE_IDENTIFIER | 88.9 | 100.0 |
| NO_CATEGORY | 95.7 | 62.9 |
| Weighted Average | 88.7 | 89.6 |

TABLE VI. SOURCE CATEGORY CROSS VALIDATION

| Category | Recall [%] | Precision [%] |
|---|---|---|
| ACCOUNT | 85.7 | 100.0 |
| AUDIO | 100.0 | 100.0 |
| BROWSER | 50.0 | 100.0 |
| CALENDAR | 100.0 | 100.0 |
| CONTACT | 91.7 | 100.0 |
| FILE | 60.0 | 100.0 |
| LOG | 100.0 | 71.4 |
| NETWORK | 72.7 | 88.9 |
| NFC | 100.0 | 100.0 |
| PHONE_CONNECTION | 75.0 | 85.7 |
| PHONE_STATE | 100.0 | 100.0 |
| SMS_MMS | 96.3 | 100.0 |
| SYNC | 80.0 | 100.0 |
| SYSTEM | 80.6 | 89.3 |
| VOIP | 66.7 | 100.0 |
| NO_CATEGORY | 97.1 | 70.2 |
| Weighted Average | 85.7 | 88.0 |

TABLE VII. SINK CATEGORY CROSS VALIDATION

S. Rasthofer, S. Arzt, and E. Bodden, “A machine-learning approach for classifying and categorizing android sources and sinks,” NDSS, 2014.

# Epicc

```
1 private OnClickListener mMyListener =
2     new OnClickListener() {
3   public void onClick(View v) {
4     Intent intent = new Intent();
5     intent.setAction("a.b.ACTION");
6     intent.addCategory("a.b.CATEGORY");
7     startActivity(intent); } };
```

Figure 2: Example of implicit Intent communication

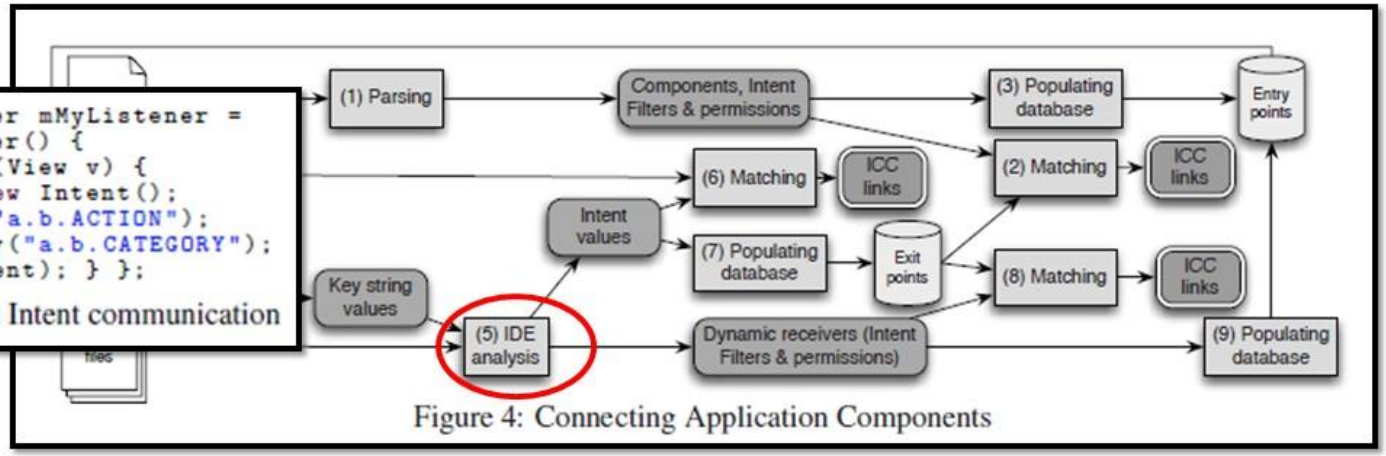


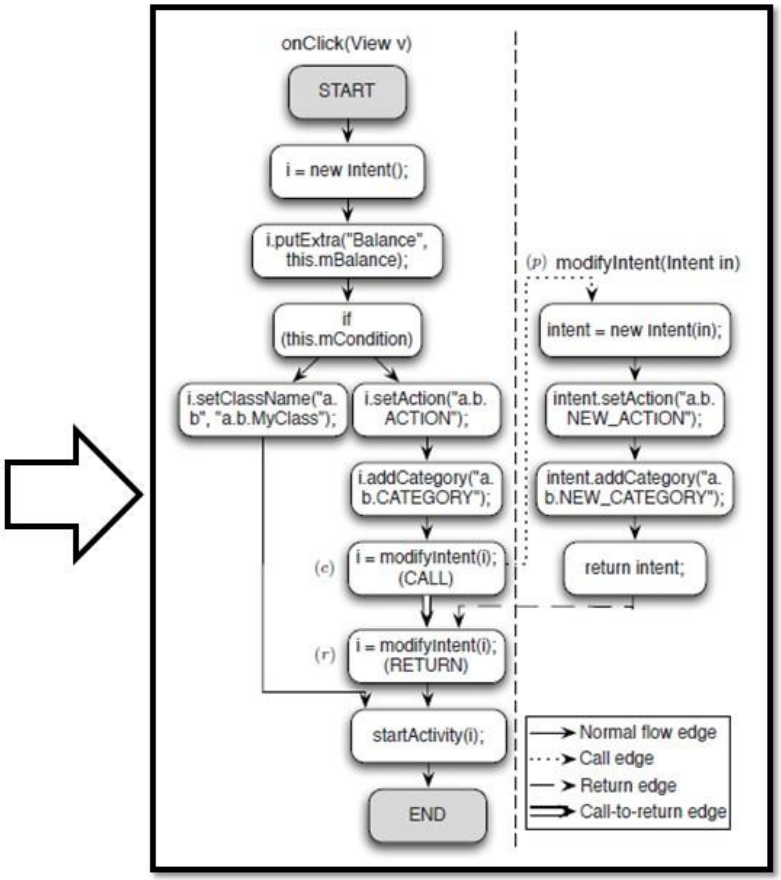

Figure 4: Connecting Application Components

IDE： Inter-procedural Distributive Environment

Octeau D, McDaniel P, Jha S, et al. Effective inter-component communication mapping in android: An essential step towards holistic security analysis[C]//22nd {USENIX} Security Symposium ({USENIX} Security 13). 2013: 543-558.

# Epicc

```
1  public void onClick(View v) {
2    Intent i = new Intent();
3    i.putExtra("Balance", this.mBalance);
4    if (this.mCondition) {
5      i.setClassName("a.b",
           "a.b.MyClass");
6    } else {
7      i.setAction("a.b.ACTION");
8      i.addCategory("a.b.CATEGORY");
9      i = modifyIntent(i);
10   }
11   startActivity(i); }
12
13 public Intent modifyIntent(Intent in) {
14   Intent intent = new Intent(in);
15   intent.setAction("a.b.NEW_ACTION");
16   intent.addCategory("a.b.NEW_CATEGORY");
17   return intent; }
```



# FlowDroid

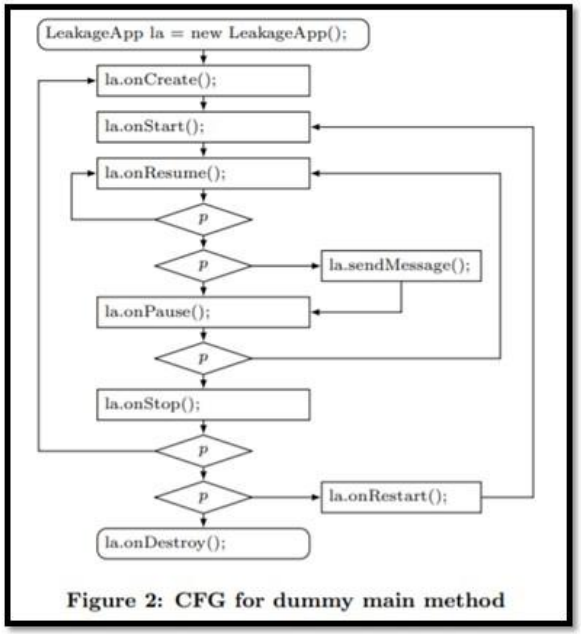



**Figure 2: CFG for dummy main method**

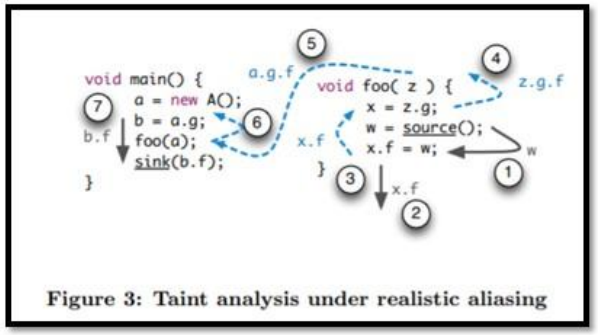



**Figure 3: Taint analysis under realistic aliasing**

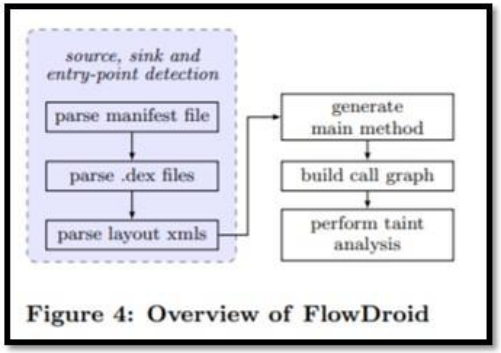



**Figure 4: Overview of FlowDroid**

Arzt, S., Rasthofer, S., Fritz, C., Bodden, E., Bartel, A., Klein, J., Le Traon, Y., Octeau, D. and McDaniel, P., 2014. Flowdroid: Precise context, flow, field, object-sensitive and lifecycle-aware taint analysis for android apps. Acm Sigplan Notices, 49(6), pp.259-269.

# AmanDroid

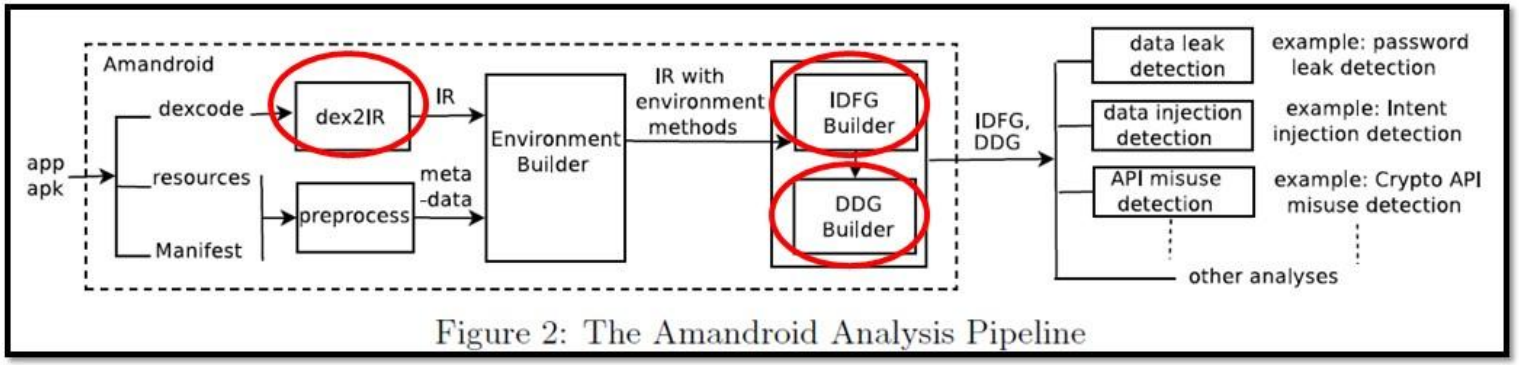



Figure 2: The Amandroid Analysis Pipeline

- IDFG: inter-component data-flow graph
- DDG： data dependence graph

Wei F, Roy S, Ou X. Amandroid: A precise and general inter-component data flow analysis framework for security vetting of android apps[C]//Proceedings of the 2014 ACM SIGSAC conference on computer and communications security. 2014: 1329-1341.

# IccTA

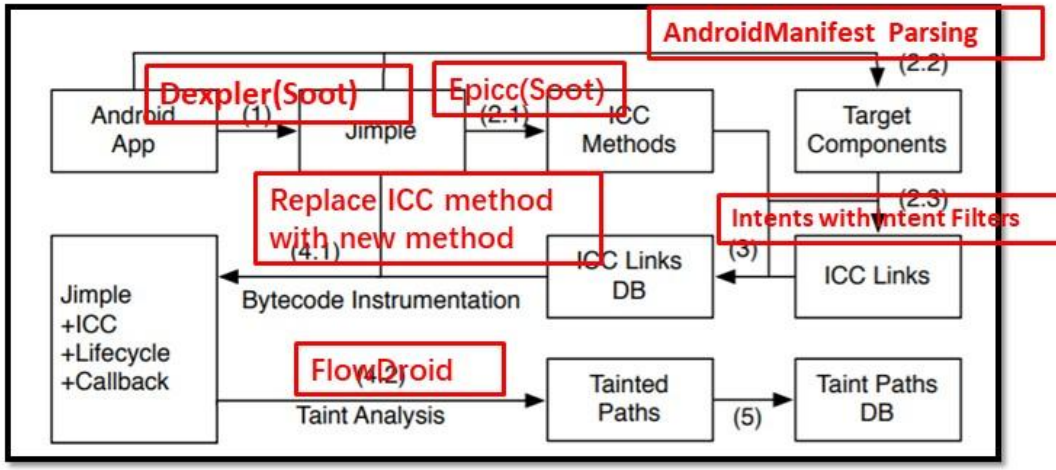
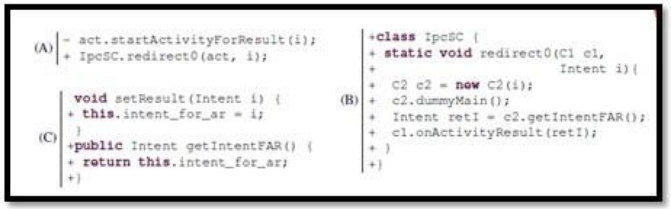



TABLE I
THE TOP 8 USED ICC METHODS. WHEN THESE METHODS ARE OVERLOADED, WE CONSIDER THE ONE WITH MOST NUMBER OF CALLS.

| ICC Method | # of Calls | # of Apps |
|---|---|---|
| startActivity | 54,334 (56.01%) | 1,972 (96.4%) |
| startActivityForResult | 11,118 (11.46%) | 1,409 (68.7%) |
| query | 8,191 (8.44%) | 1,374 (67.2%) |
| startService | 6,660 (6.86%) | 1,597 (78.1%) |
| sendBroadcast | 5,119 (5.28%) | 1,035 (50.1%) |
| insert | 2,164 (2.23%) | 780 (38.1%) |
| bindService | 1,638 (1.69%) | 512 (25.0%) |
| delete | 1,633 (1.69%) | 472 (23.1%) |
| Other ICC Methods | 6,155 (6.34%) | - |
| Total | 97,012 (100%) | - |




Li, L., Bartel, A., Bissyandé, T.F., Klein, J., Le Traon, Y., Arzt, S., Rasthofer, S., Bodden, E., Octeau, D. and McDaniel, P., 2015. Iccta: Detecting inter-component privacy leaks in android apps. In 37th IEEE International Conference on Software Engineering, 1, pp. 280-291.

# DroidSafe

Android Device Implementation (ADI)

```
1  package android.os;
2  public class Bundle ... {
3    private Map<String,Object> mMap =
4                  new HashMap<String,Object>(); (H)
5
6    public void put(String k, Object v) {
7      mMap.put(k,v);
8    }
9
10   public Object get(String k) {
11     return mMap.get(k);
12   }
13 }
```

```
1  package java.util;
2  public class HashMap<K,V>... {
3    private Entry[] table = new Entry[size]; (T)
4
5    public void put(K key, V value) {
6      ...
7      table[index] = new Entry<K,V>(key, value); (E)
8    }
9
10   public V get(Object key) {
11     ...
12     e = table[indexFor(hash, table.length)];
13     ...
14     return e;
15   }
16 }
```

Android Application Source Code

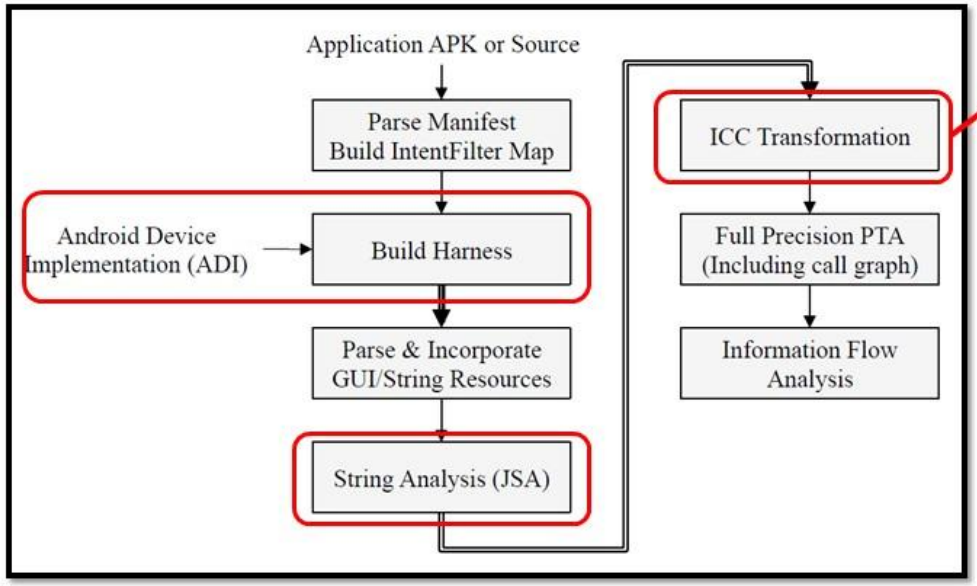
```
1  public class Activity1 extends Activity {
2    ...
3    Bundle bundle1 = new Bundle(); (N)
4    bundle1.put("data", <notSensitive>);
5    ...
6    sink(bundle1);  //not a sensitive flow
7  }
```

```
1  public class Activity2 extends Activity {
2    ...
3    double sensitive = location.getLatitude(); //source
4    Bundle bundle2 = new Bundle(); (S)
5    bundle2.put("data", sensitive);
6    ...
7    sink(bundle2);  //flow of sensitive -> sink
8  }
```

Fig. 2. Example source code for our ADI and two `Activity` objects illustrating the challenges of points-to and information flow analysis.

Gordon, M.I., Kim, D., Perkins, J.H., Gilham, L., Nguyen, N. and Rinard, M.C., 2015. Information flow analysis of android applications in droidsafe. In NDSS, 15 (201), p. 110.

# DroidSafe




| Source Method | Target Method Call Injected |
|---|---|
| Context: void send+Broadcast(Intent, ...) [6 variants] | BroadcastReceiver: void onReceive(Intent) |
| Activity: void startActivit+(Intent, ...) [6 variants] | Activity: void setIntent(Intent) |
| Context: void bindService(Intent, Connection) | Service: void droidSafeOnBind(Intent, Connection) |
| Context: void startService(Intent) | Service: void onStartCommant(Intent, ...) |
| ContentResolver: insert, query, delete, update | ContentProvider: insert, query, delete, update |

Fig. 3. DroidSafe's ICC source to target methods transformations.

- **Accurate analysis stubs for 3,176 native methods, using hook technique**
- **Inject taint on method's arguments and return value for parsing Reflection**

Gordon, M.I., Kim, D., Perkins, J.H., Gilham, L., Nguyen, N. and Rinard, M.C., 2015. Information flow analysis of android applications in Droidsafe. In NDSS, 15 (201), p. 110.

# RAICC（atypical ICC）

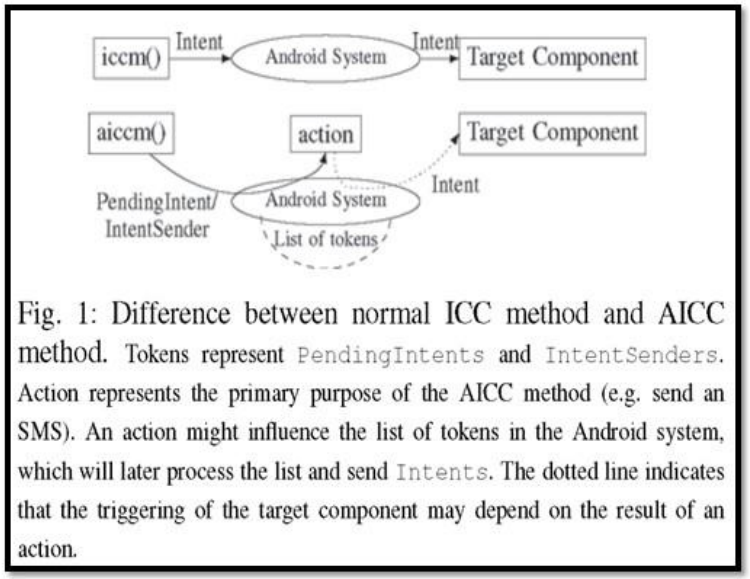



Fig. 1: Difference between normal ICC method and AICC method. Tokens represent `PendingIntents` and `IntentSenders`. Action represents the primary purpose of the AICC method (e.g. send an SMS). An action might influence the list of tokens in the Android system, which will later process the list and send `Intents`. The dotted line indicates that the triggering of the target component may depend on the result of an action.

```
1  public void reconnectionAttempts() {
2    Calendar cal = Calendar.getInstance();
3    cal.add(12, this.elapsedTime);
4    Intent i = new Intent(this, AlarmListener.class);
5    intent.putExtra("alarm_message", "Wake up Dude !");
6    PendingIntent pi = PendingIntent.getBroadcast(this,
     ↪  0, i, 134217728);
7    AlarmManager am = (AlarmManager)
     ↪  getSystemService("alarm");
8    am.set(0, cal.getTimeInMillis(), pi);
9  }
```

Listing 2: A simplified example of how the method `set` of the `AlarmManager` class is used in a malware.

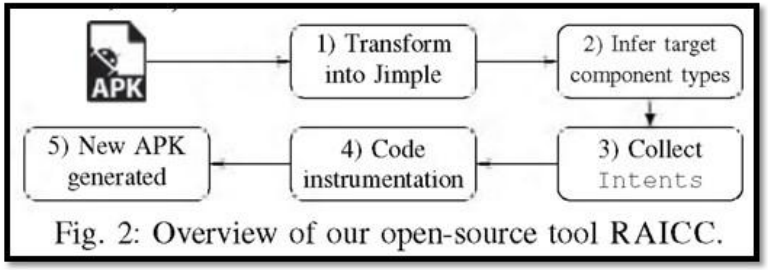



Fig. 2: Overview of our open-source tool RAICC.

Samhi J, Bartel A, Bissyandé T F, et al. RAICC: Revealing Atypical Inter-Component Communication in Android Apps[C]//2021 IEEE/ACM 43rd International Conference on Software Engineering (ICSE). IEEE, 2021: 1398-1409.

# Analysis Tools

- Soot： Jimple；

https://github.com/soot-oss/soot

AndroGaurd： Smali；

https://github.com/androguard/androguard

- Gator： http://web.cse.ohio-state.edu/presto/software/gator/

# The End

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过辰楷