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ANDetect: A Third-party Ad Network Libraries Detection Framework for Android Applications

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December 5, 2023

Artifacts Evaluated acm Functional V1.1

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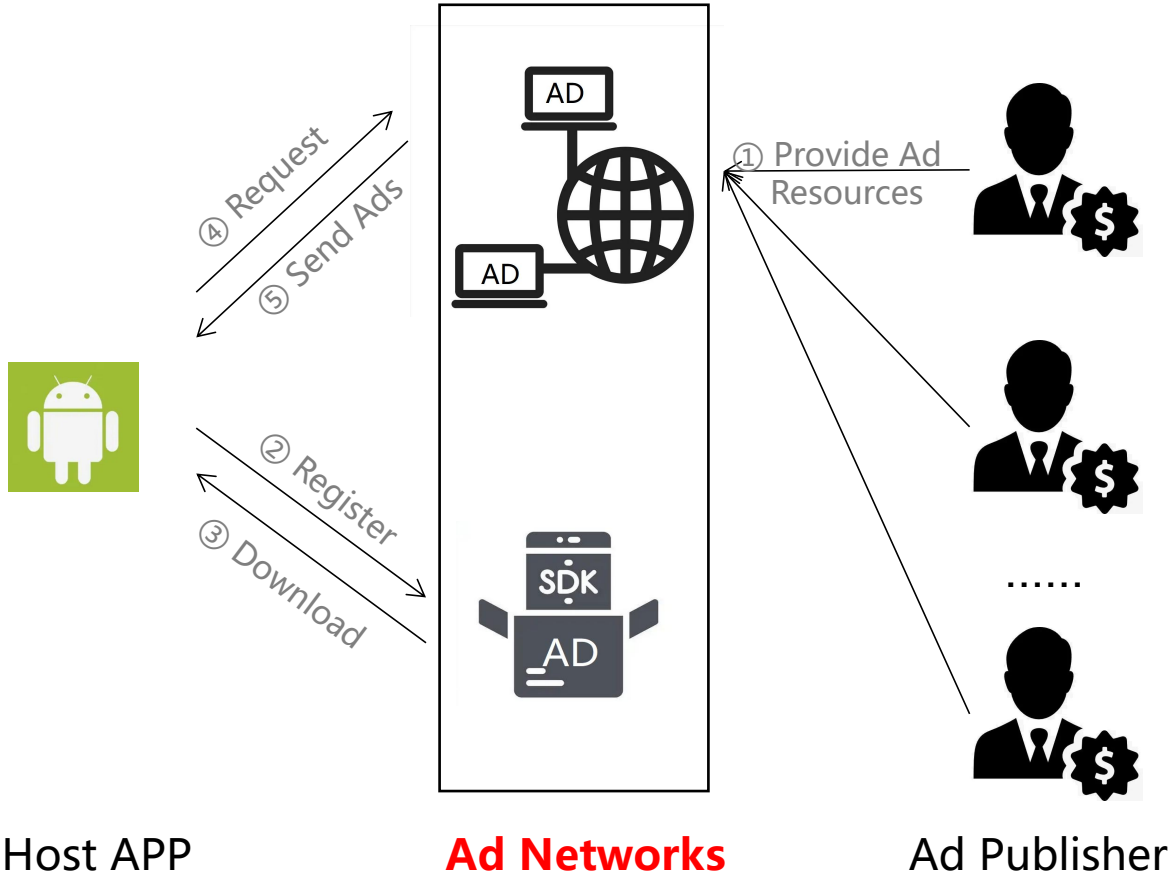
Advertising Networks



Meta

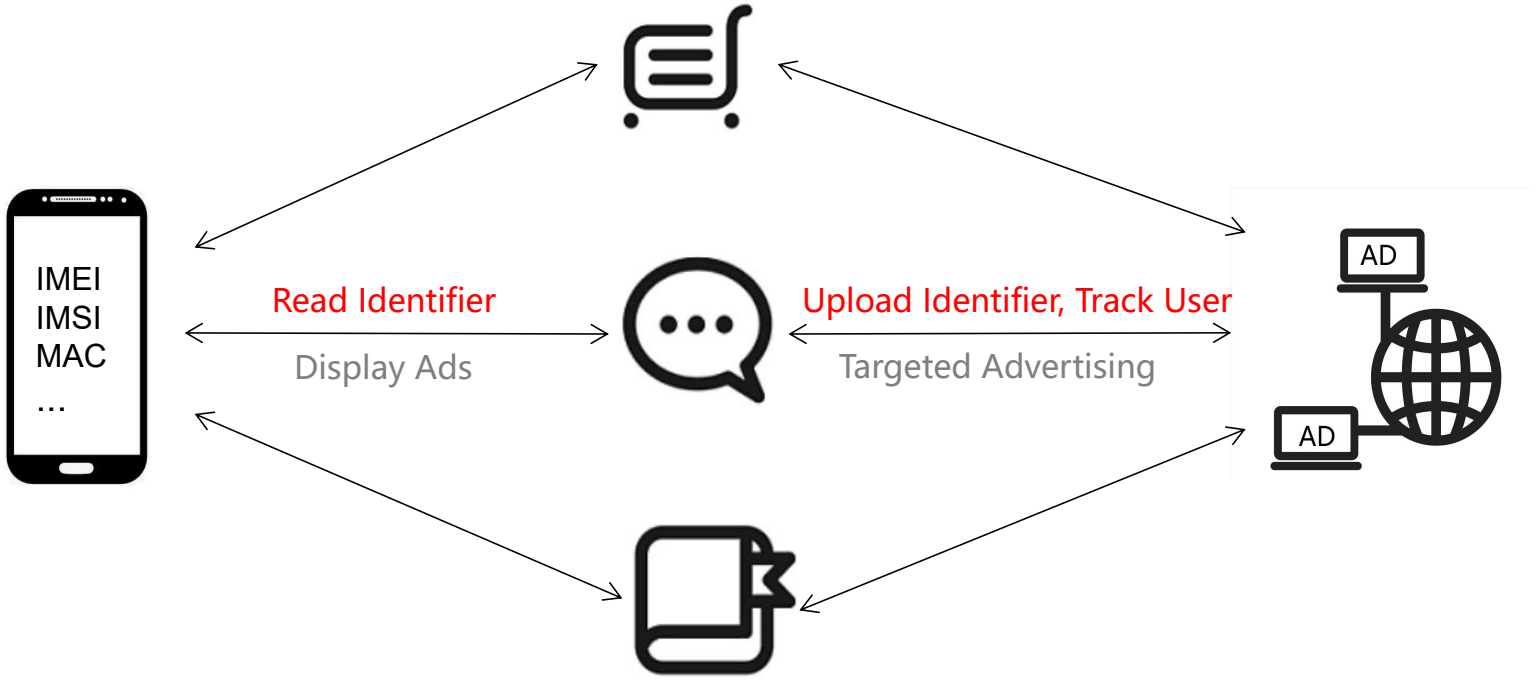
APPLOVIN

Google AdMob

Yandex

Why Detect Ad Network Libs?

A1: Protect user's privacy.



Tracking

⬇

Analyzing

⬇

User Portrait

...

Why Detect Ad Network Libs?

A2: Identify adware effectively.

Adware is a type of malicious software that secretly installs itself on your device and displays unwanted advertisements and pop-ups.

APP Obfuscation and Encryption

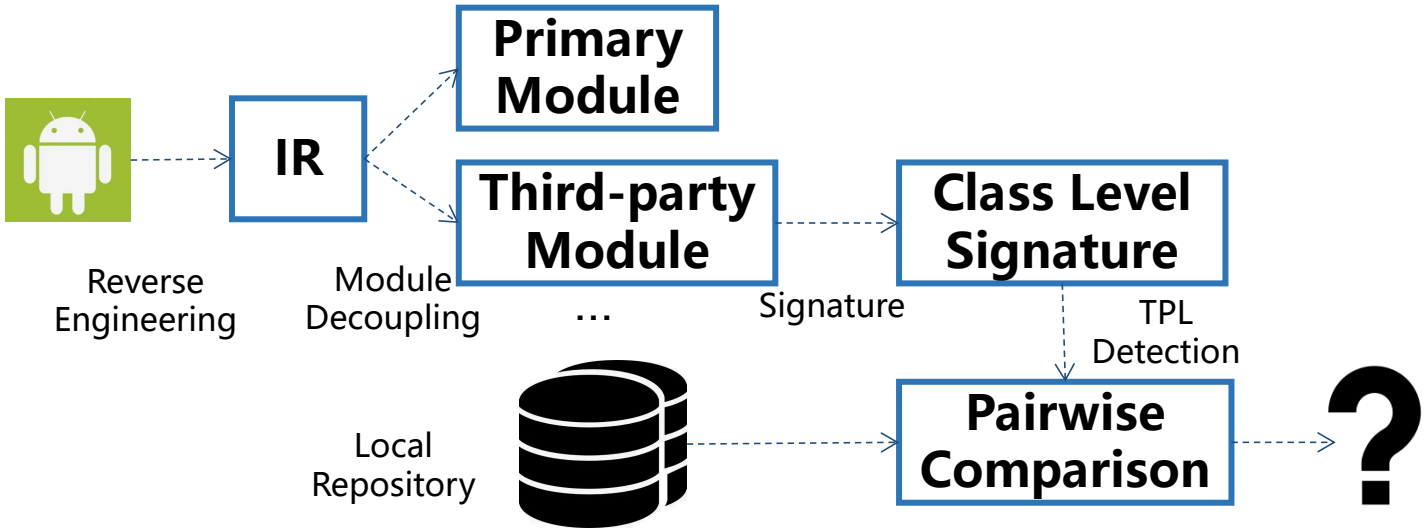
Identifier Renaming	APP Obfuscation	allatori, DashO, DexGuard, ProGuard
String Encryption		
Package Flattening		
Dead Code Removal		
Dex Encryption	APP Encryption	Qihoo, APKProtect

…

Existing Work

Recognize TPL

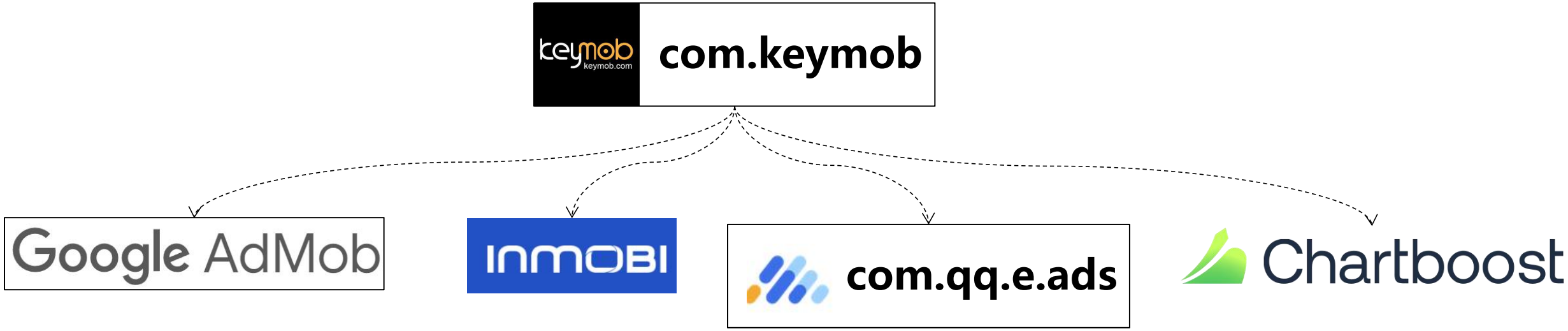
- LibRadar (ICSE’16)
- LibScout (CCS’16)
- LibD (ICSE’17)
- LibLoad (TMC’22)



- The essence of these works is whitelist-based method.
- None of these works can detect the ad libs in an encrypted APK.

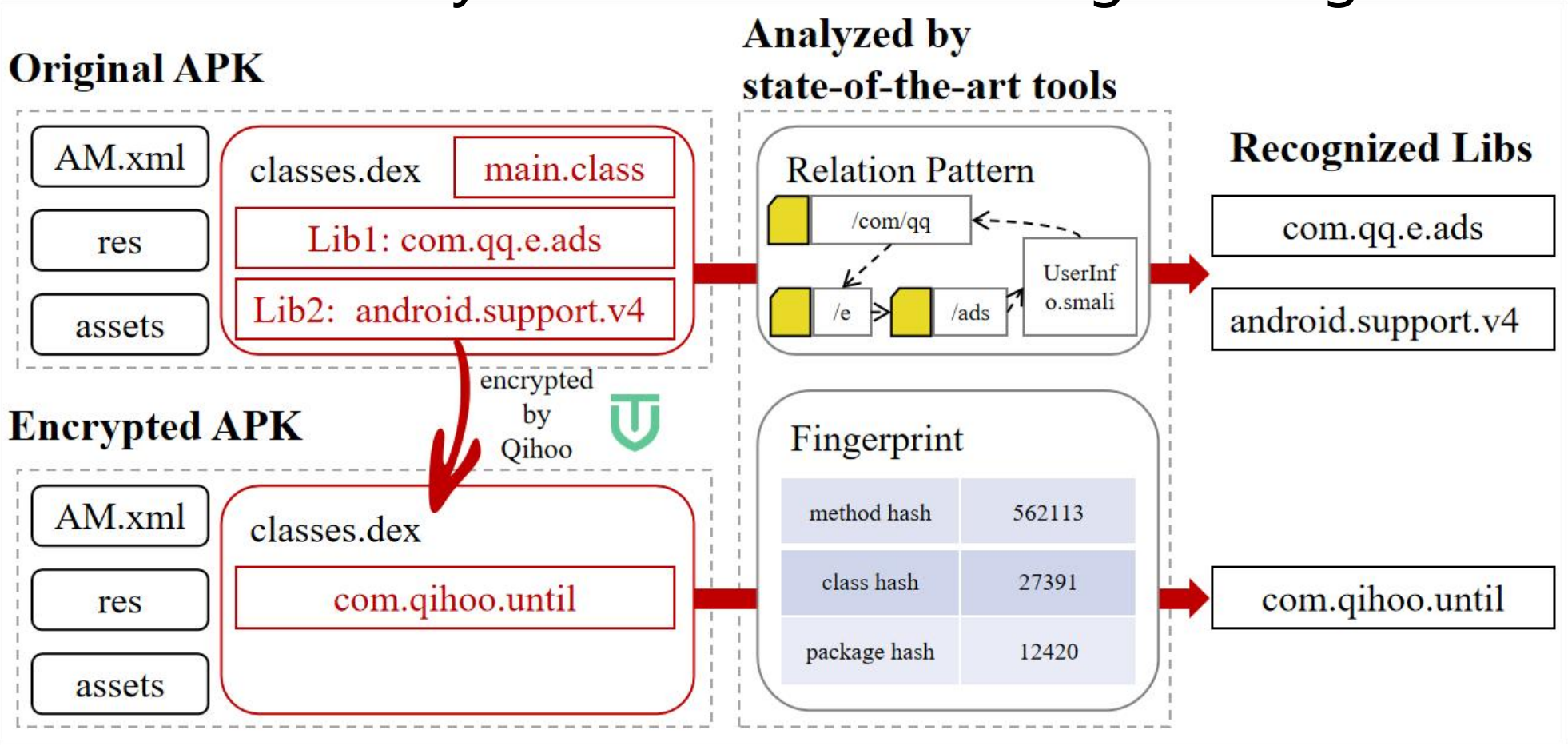
Challenges

C1: Some integrated ad network libraries may be incorporated by many single ad libraries. Traditional whitelist-based methods fail.



Challenges

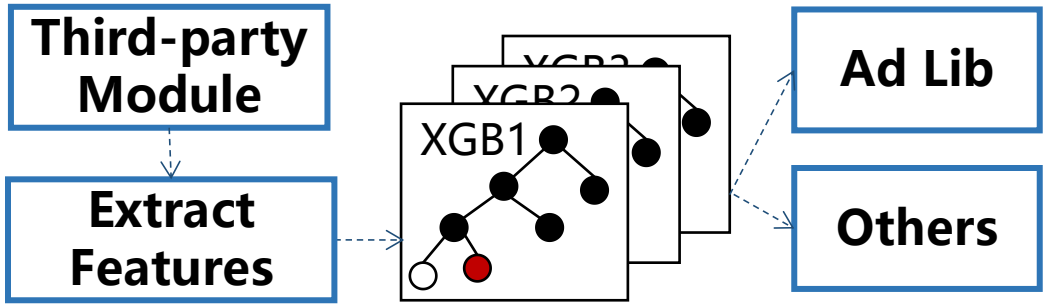
C2: The encryption of APP is always used by developers to enhance security and deter reverse engineering.

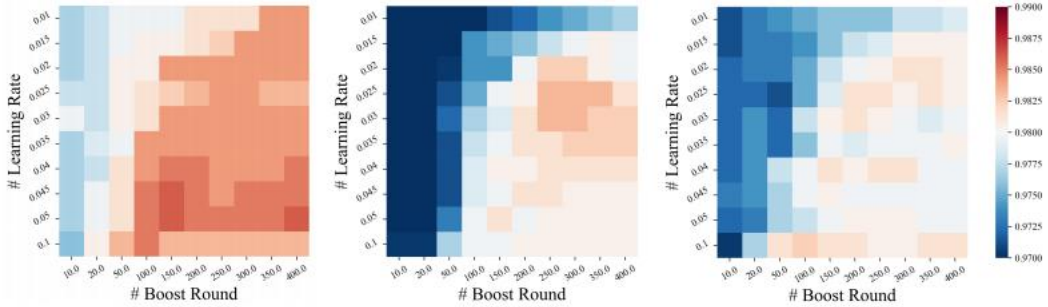


Break the Limitation of Whitelist

C1: Some integrated ad network libraries may be incorporated by many single ad libraries. Traditional whitelist-based methods fail.

- **Extract the features of system API.**
  - API count
  - Distribution across classes
  - Distribution across methods
- **Train 3 Xgboost models with Dataset_{AN} and Dataset_{NAN}.**
  - 833 ad libraries
  - 2758 non-ad libraries
- **Integrate the models and classify every third-party module.**





(a) API count (b) DIST across classes (c) DIST across methods

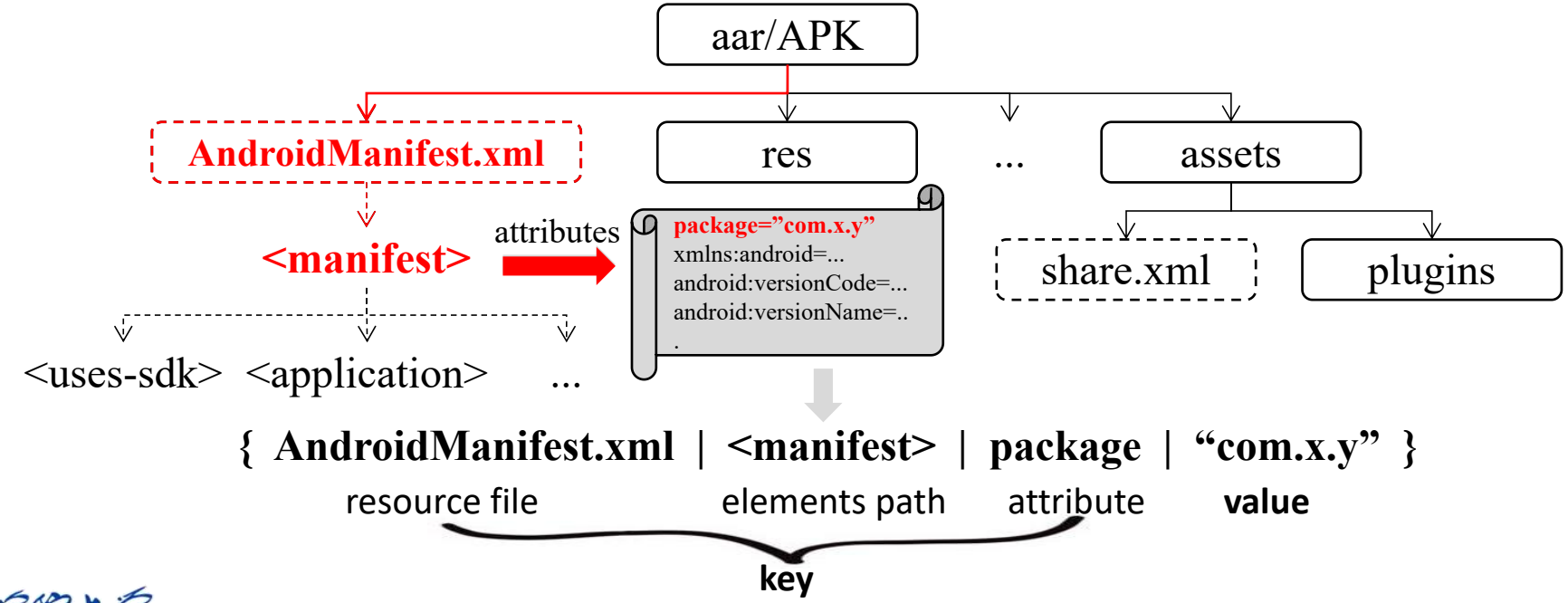
Address the Challenge of Encrypted APPs

C2: The encryption of APP is always used by developers to enhance security and deter reverse engineering.

- **Utilize the resource features of encrypted APPs.**

- **Resource Features**
  - AndroidManifest.xml
  - files in *res*
  - files in *assets*

- **Key-value Mapping**
  - resource file
  - elements path
  - attribute



Address the Challenge of Encrypted APPs

Q: How to choose suitable resource features and how to match?

- **Universality.**

$$U_k = \frac{\sum_{i=1}^{l} In_{k,K_i}}{l}, \quad In_{k,K_i} = \begin{cases} 1, & k \in K_i \\ 0, & k \notin K_i \end{cases}$$

- **Differentiation.**

$$d_{v,i} = \max_{e \in v}\{\frac{f_{e,i}}{\sum_{e' \in e_i} f_{e',i}} \times \ln \frac{l}{1 + \sum_{j=1}^{l} In_{e,e_j}}\}$$

$$D_k = \frac{\sum_{i=1}^{l} \sum_{v \in M_{k,i}} d_{v,i}}{\sum_{i=1}^{l} |M_{k,i}|}$$

- **Insensitivity.**

$$IS_k = \frac{\sum_{i=1}^{|an_k|} \frac{1}{|v_{k,i}|}}{|an_k|}$$

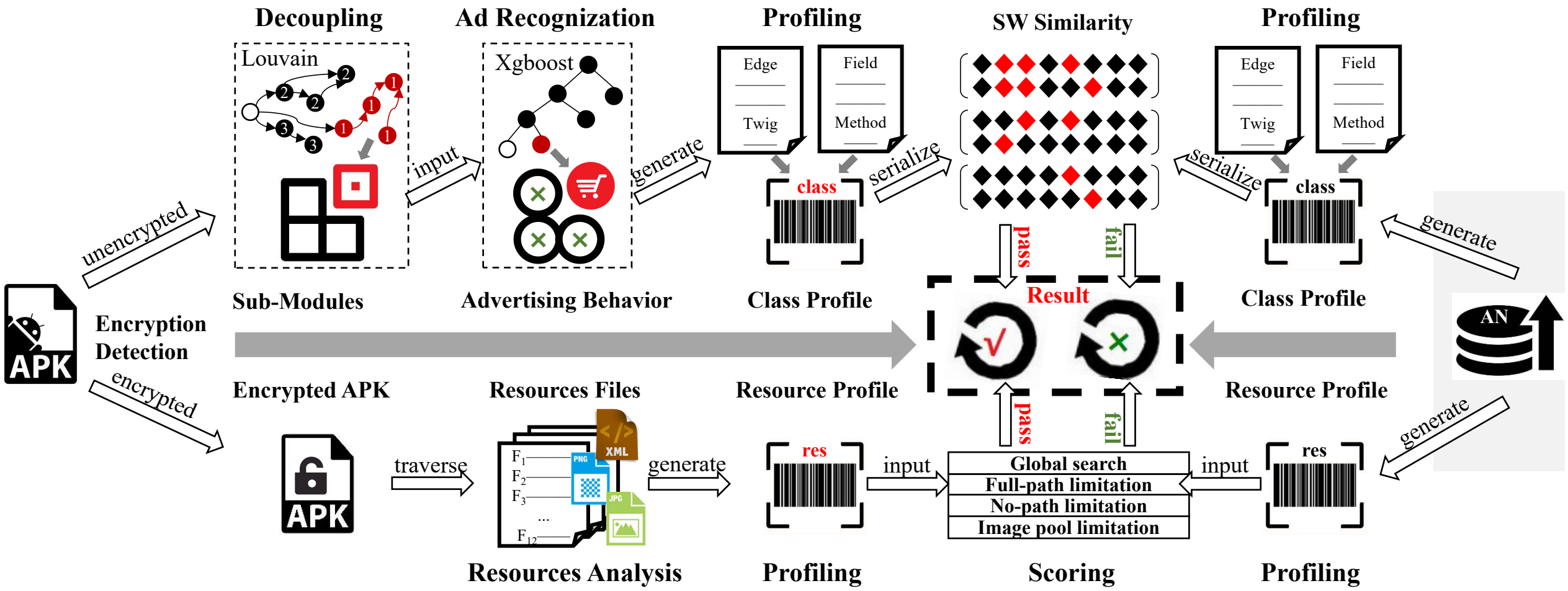
Table 5: The key, universality, differentiation and insensitivity of each feature.

Feature	Key	U_k	D_k	IS_k
F_1	AndroidManifest.xml_manifest_package	1.0000	0.7294	0.7913
F_2	AndroidManifest.xml_manifest uses-permission_android:name	0.5385	0.1122	0.3215
F_3	AndroidManifest.xml_manifest application provider_android:authorities	0.1186	0.0517	0.7953
F_4	AndroidManifest.xml_manifest application receiver intent-filter action_android:name	0.1602	0.0648	0.7222
F_5	AndroidManifest.xml_manifest application activity_android:name	0.3960	0.4886	0.4251
F_6	AndroidManifest.xml_manifest application service_android:name	0.1609	0.3541	0.5326
F_7	AndroidManifest.xml_manifest application receiver_android:name	0.1943	0.3261	0.6667
F_8	res\values\values.xml_resources dimen_name	0.1350	0.1666	0.1018
F_9	res\values\values.xml_resources string_name	0.3770	0.2886	0.2112
F_{10}	res\values\values.xml_resources declare-styleable attr_name	0.1302	0.3541	0.1628
F_{11}	res\values\values.xml_resources style_name	0.2529	0.1062	0.3273

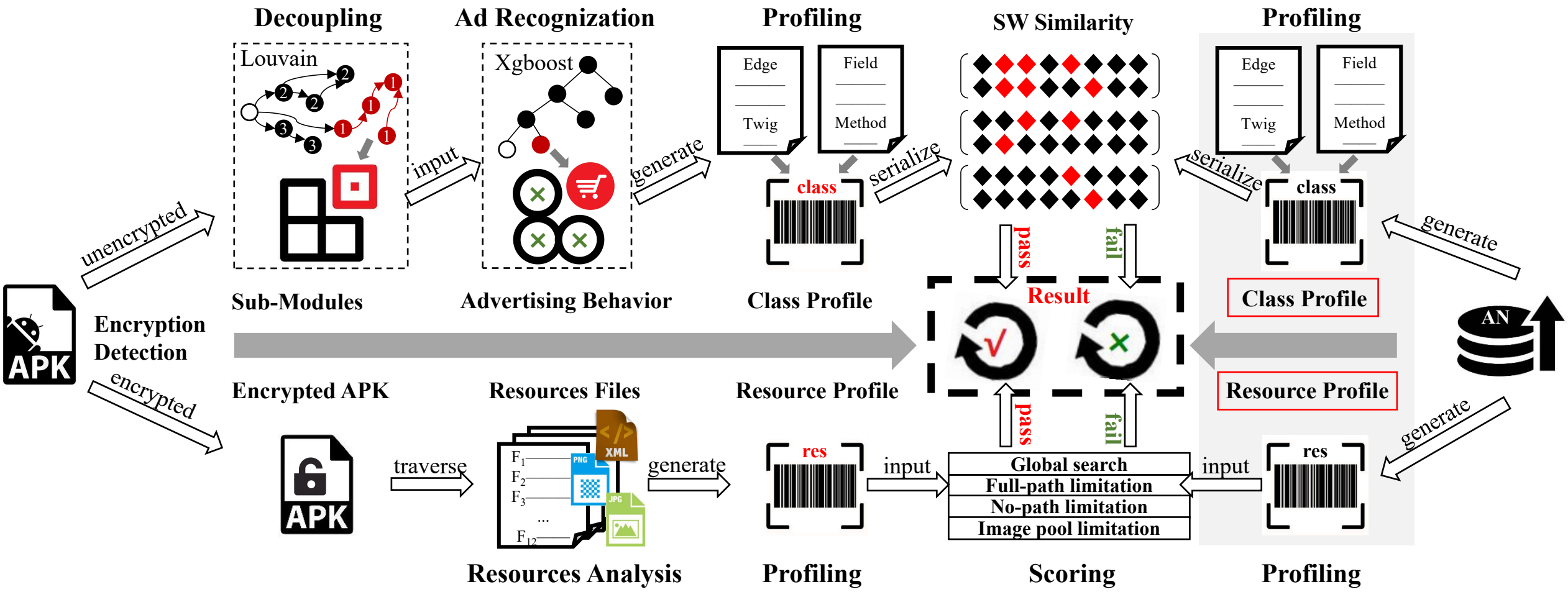
Global search | **Full-path match** | **No-path match** | **Image pool**

Comprehensive scoring

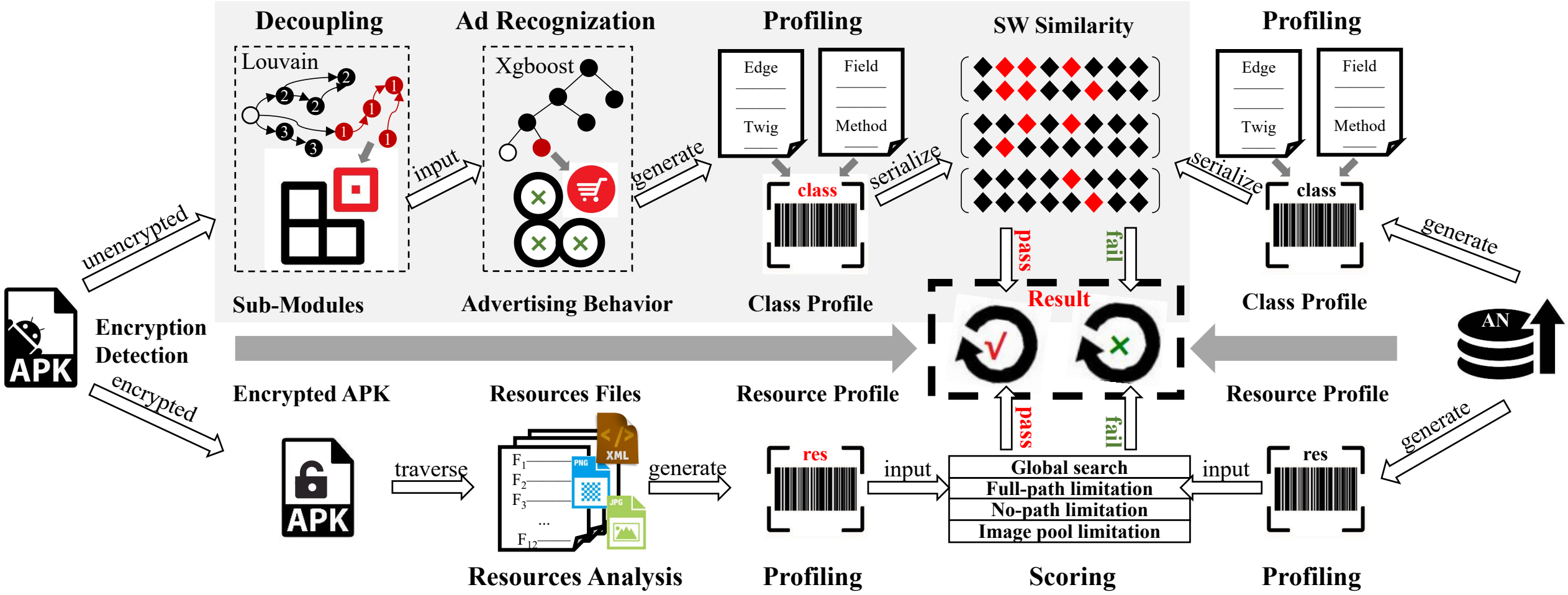
Architecture of ANDetect



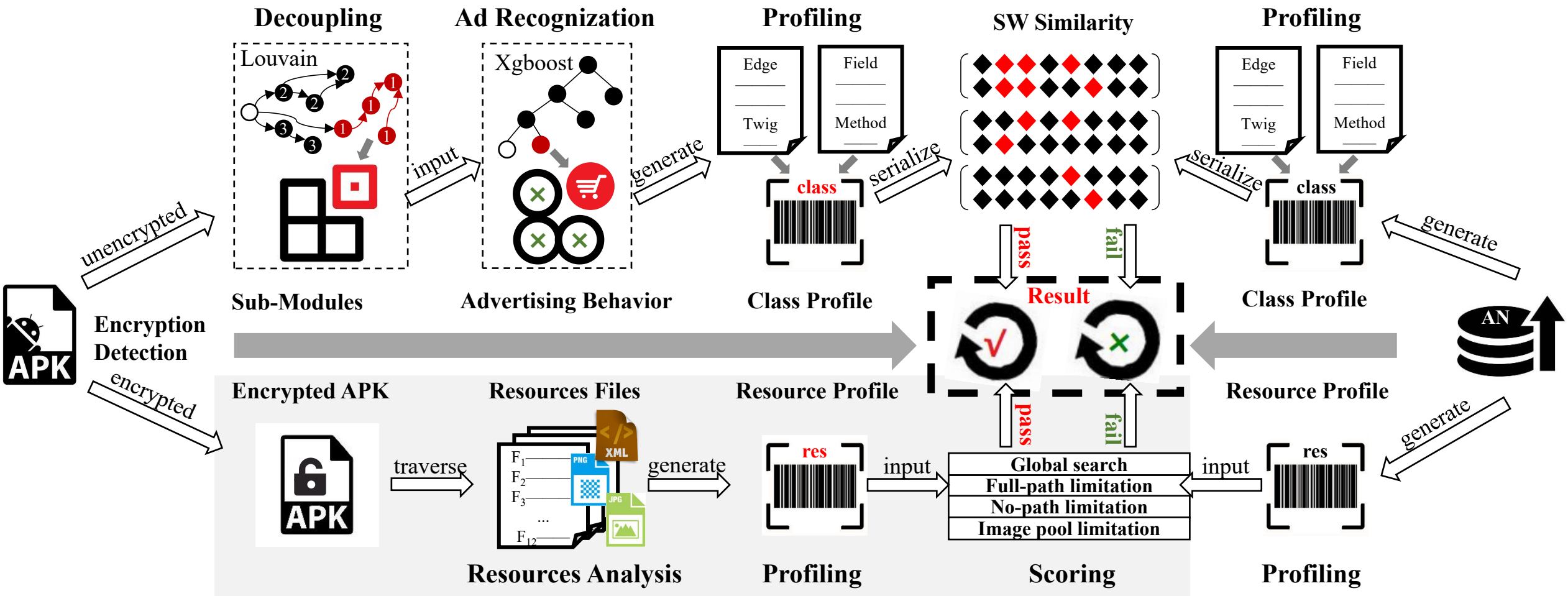
Architecture of ANDetect



Architecture of ANDetect



Architecture of ANDetect



Datasets

- **Evaluation metrics**
- **Fine-grained True Positive(TP-FG)**
- **Coarse-grained True Positive(TP-CG)**
- **Precision**
- **Recall**

- **Datasets**
- **Android Application Dataset(20,000 adwares & 125,401 unlabeled APPs)**
  - Low-confidence labeled datasets
  - High-confidence labeled datasets
- **Ad Networks Dataset(833 Ad libs & 2758 non-ad libs)**

Evaluation

Performance of ANDetect:

- Leveraging a 2:1 mix of non-encrypted and encrypted applications.
- Compare with **LibD**, **LibRadar** and **LibScout**.
- **Low Precision:** extra ad libs
- **High Recall:** competitors' misclassification of *com.google.android.gms.ads*

Table 1: The performance of ANDetect compared with other three tools in the experimental environment.

Tools	TP-CG	TP-FG	Precision	Recall	Time(s)/AP
LibD	46.08%	78.31%	99.72%	78.31%	58.14
LibRadar	48.04%	77.86%	99.50%	77.86%	29.37
LibScout	25.49%	72.64%	99.54%	72.64%	74.54
ANDetect	95.10%	95.97%	95.84%	95.97%	34.07

Table 2: The performance of ANDetect compared with other three tools in the real-world environment.

Tools	TP-CG	TP-FG	Precision	Recall	Time(s)/AP
LibD	47.40%	62.67%	98.73%	62.67%	153.45
LibRadar	43.35%	59.69%	98.26%	59.69%	65.11
LibScout	32.37%	53.47%	99.79%	53.47%	246.51
ANDetect	93.64%	93.08%	97.29%	93.08%	69.24

Evaluation

Robustness in encrypted APP detection:

- Randomly select 100 non-encrypted APPs with **resource confusion**.
- Tagged by the combined outputs of LibScout, LibD and LibRadar (**Low-confidence**)
- Identify the ad libs through **ANDetect's encrypted APP detection module**

- **Resource confusion properties:**
  - *res* directory is absent;
  - over half of the file names in *res* comprise less than 5 characters;
  - over half of the file names in *color* or *xml* comprise less than 5 characters;

Table 3: The result of encrypted application detection in resource confused applications.

Dataset	size	TP-CG	TP-FG	Precision	Recall
AP'_{adware}	100	94.00%	86.24%	81.84%	86.24%
AP'_{truth}	100	94.74%	91.50%	72.27%	91.50%

Evaluation

Novel ad libraries:

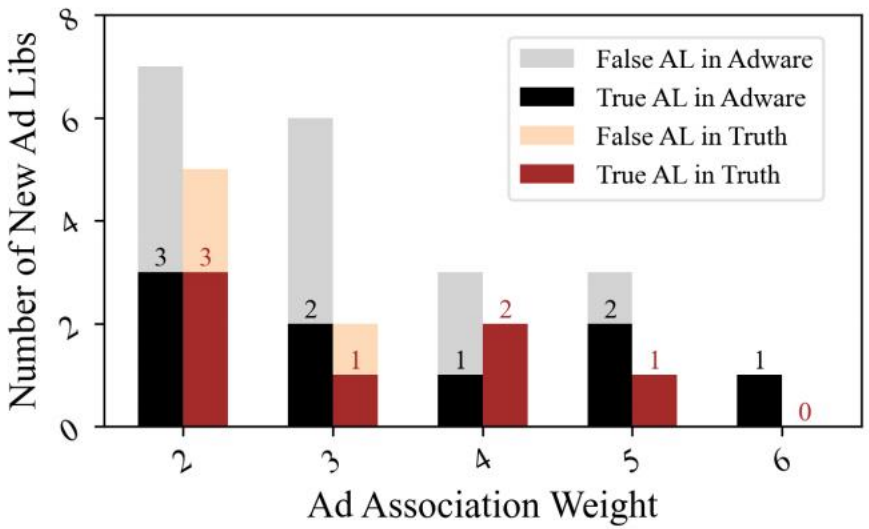


Figure 5: The novel ad libraries detected by ANDetect. The number of genuine ALs and false positives from AP_{adware} and AP_{truth} are given respectively.

- ANDetect’s non-encrypted application detection module
- Discern the true ad libs:
  - ◆ define ad association weight
  - ◆ search new lib name in Google
  - ◆ compute associate weight
- Allow for false positive to identify more novel ad libs
- **16** novel ad libs

Evaluation

Novel adwares:

- Label 20,000 adwares using VT
- Relationship between ad libs and adware

Table 4: The candidates of malicious ALs.

Candidate ALs	VirusTotal's Label	Relevance
com.adsmogo	Adware.ADWARE/ANDR.AdMogo	0.50
net.youmi.android	Android.Adware.Youmi.A	0.47
com.mopub.mobileads	AdLibrary:MoPub	0.45
com.inmobi.ads	AdWare.AndroidOS.Inmobi	0.80
com.nd.dianjin	Android.Dianjin.A (PUP)	0.50
cn.smartmad	Android.Adw.SmartMad	0.12
cn.domob.android	Android.Domob.A (AdWare)	0.26
com.kuguo.ad	Andr.Adware.Kuguo-4	1.00
com.jirbo.adcolony	Adware/AdColony!Android	0.50
com.sixth.adwoad.mraid	ADWARE/ANDR.AdsWo.FAN.Gen	0.43
org.iqiyi.video	AdWare.AndroidOS.IqiAd.a	1.00
com.revmob	Adware.Revmob.1.origin	0.20

Table 7: The brand-new adware detected by ANDetect. The sha256 of each adware and malicious ALs it contains are provided.

sha256	Malicious ALs
0002CA163461C26D3EA1D7384DB1833D4002CA679D0BA1906494E1BB24A95896	com.mopub.mobileads
00120DAD331324ED394118079BCB91D2B3F69C42E3C5135303DA50272FAE45F7	com.inmobi.ads;com.mopub.mobileads
00154456B10D6BF1F16DA14267D6063DAABEC20FFD28ABAB942D7BBD266D430F	com.mopub.mobileads
0134CE0FC74B7DDD800CF772A1742F7966FA4D5762359D2E6D15BED8728CC779	com.mopub.mobileads
0120397B85BFF474D554F82BEC39A5AB9827F93B68FD505AF89B935497860BAE	com.mopub.mobileads
0137F1EBE1F012BF454F78FE2452C1D39E0105AD0A00AC9E90F799EC96D09406	com.mopub.mobileads
7C90D85F5E08639CA32A5473CBDBE1B60334634B5CDB5AA7274FFF7A3B7B9BEA	com.mopub.mobileads
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7CC341B217FA38C3C12BFA008166F6F7229ABE3CB765D4AD5455925D5EB20632	com.mopub.mobileads
7CE87F293FDDCA68C5786976B7F9AF9CF37D2598B383424086066BF41814372F	com.mopub.mobileads
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A5F5AB473F93203D78F078CAC4580561609FB40D35A39CB5B78DEDCDFDBCE843	com.mopub.mobileads
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11F0B6F0FC2BE6F5826D53EA5685307201FEDAED7FEB789123D2C07E03D03B68	com.mopub.mobileads
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53 brand new adware

Summary

- **Limitation**
- Resource features do not have a clear differentiation effect like class features, which is reflected in **different versions** of ad libraries.
- Not all advertising libraries have meaningful resource features.

- **Conclusion**
- We introduce **ANDetect**, a pioneering tool designed to efficiently identify **ad libraries** in Android applications, overcoming the limitations of existing methods especially when dealing with **encrypted apps**. The experiment of ANDetect to over 140,000 apps has resulted in the detection of 16 novel ad libraries and 53 new adwares.

https://sites.google.com/view/andetect

Thank you!
Q&A

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