Reliability Analysis of Privacy Policies Based on Android Static Analysis

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Outline

- Introduction
- System Design
- Result
- Conclusion

Introduction

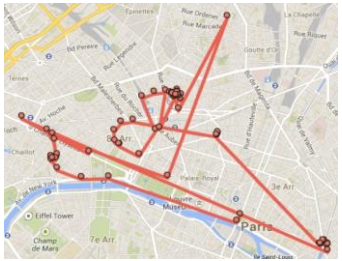
Privacy Risk in Mobile

- With the increase of mobile users, privacy issues in the mobile environment have also grown
  - Many privacy threats have received attention from mobile users and regulators

- Mobile apps collect more sensitive data than the data web collects
  - Mobile device has more personal information that identifies user contexts

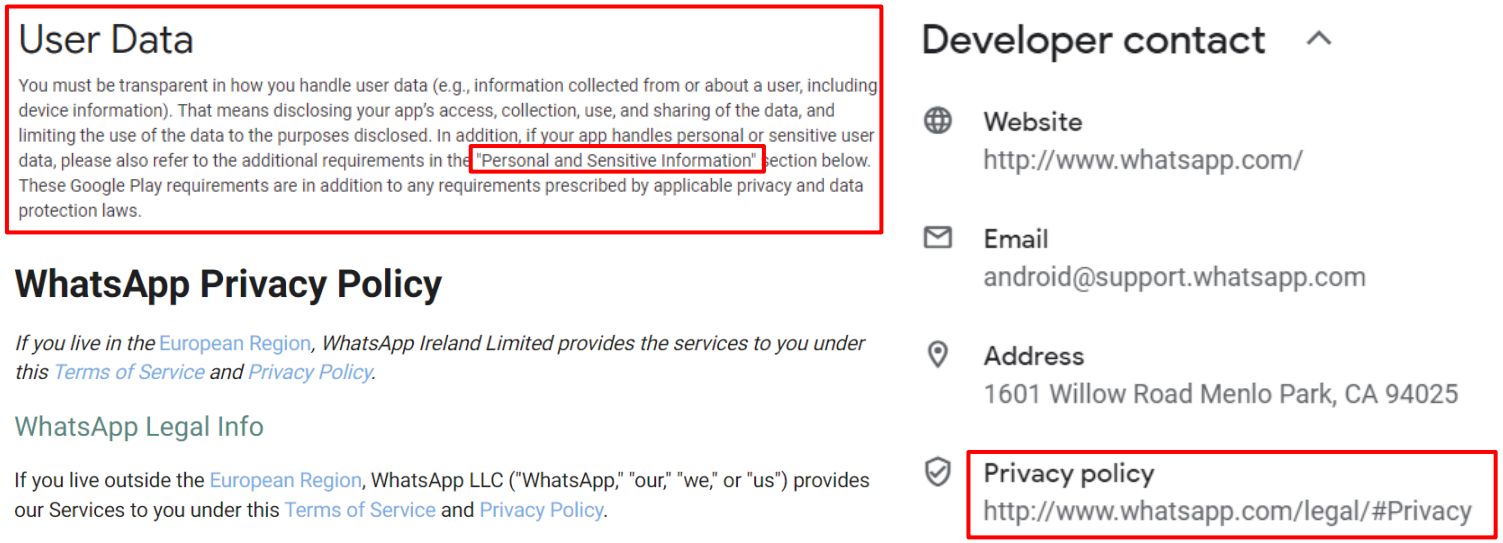
IMEI

Mobile Carrier


Location History

Privacy Policy

- On the google play store, Google requires android developers to disclose how their apps collect, use, and share user data in privacy policies
  - App users can easily know how the apps collect data by checking the privacy policy



User Data

You must be transparent in how you handle user data (e.g., information collected from or about a user, including device information). That means disclosing your app's access, collection, use, and sharing of the data, and limiting the use of the data to the purposes disclosed. In addition, if your app handles personal or sensitive user data, please also refer to the additional requirements in the "Personal and Sensitive Information" section below. These Google Play requirements are in addition to any requirements prescribed by applicable privacy and data protection laws.

WhatsApp Privacy Policy

If you live in the European Region, WhatsApp Ireland Limited provides the services to you under this Terms of Service and Privacy Policy.

WhatsApp Legal Info

If you live outside the European Region, WhatsApp LLC ("WhatsApp," "our," "we," or "us") provides our Services to you under this Terms of Service and Privacy Policy.

Developer contact

Website
http://www.whatsapp.com/

Email
android@support.whatsapp.com

Address
1601 Willow Road Menlo Park, CA 94025

Privacy policy
http://www.whatsapp.com/legal/#Privacy

Privacy Regulation

- Many strict regulations have been adopted for data protection
  - App developers modify the privacy policy to comply with the legal requirements

CCPA

GDPR

COPPA

CalOPPA

California Online Privacy Protection Act

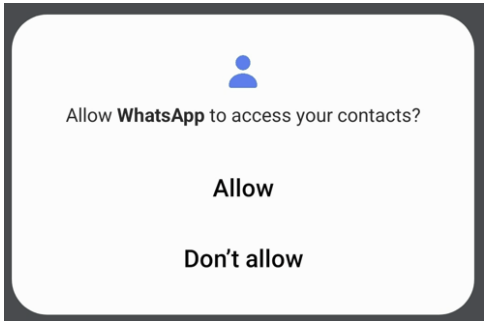
CalOPPA

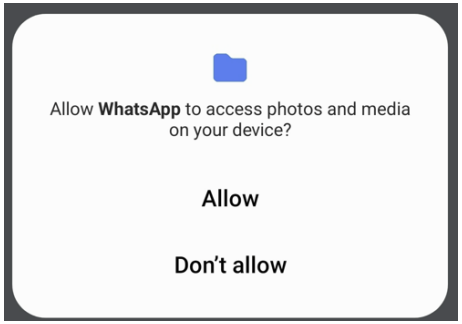
PIPEDA

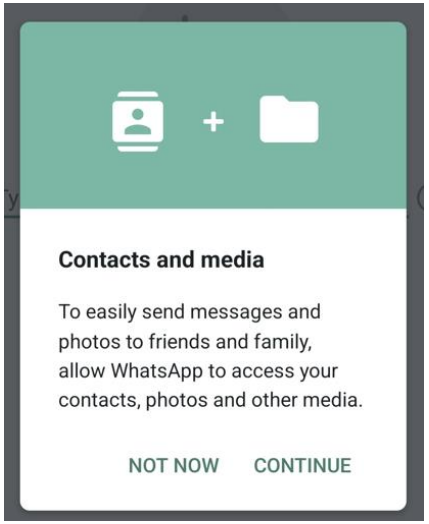
App Permission

- Previous works focus on preventing excessive requests for permissions
  - Recently developed apps require only permission of essential data

- The permissions are requested at runtime
  - Users can allow or deny permissions in person



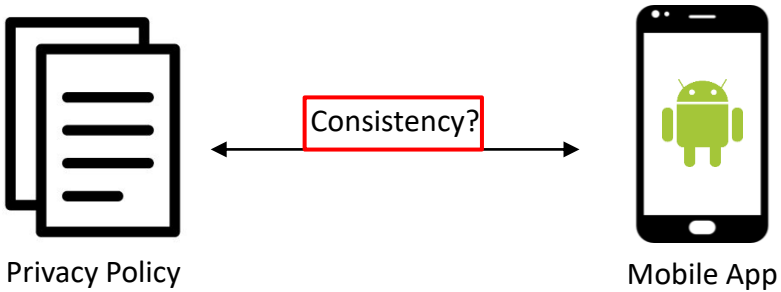




Is the Privacy Policy Reliable?

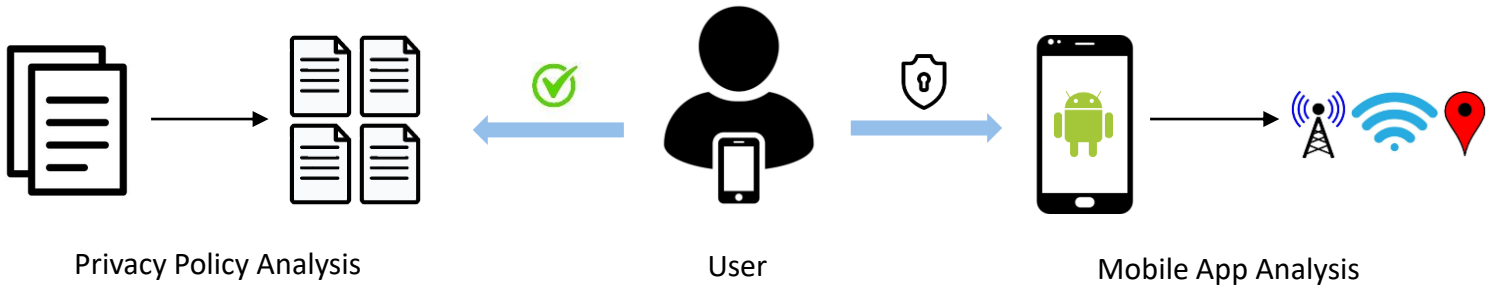
- Privacy policy is the only way to know how the app collect user data
  - Users have to rely on the privacy policy to identify the app activities

- There is no technical solution to make sure that app developers specify all of the app practices in their privacy policy
  - It may be an inconsistency in privacy policy and app practices



Policy and App Analysis

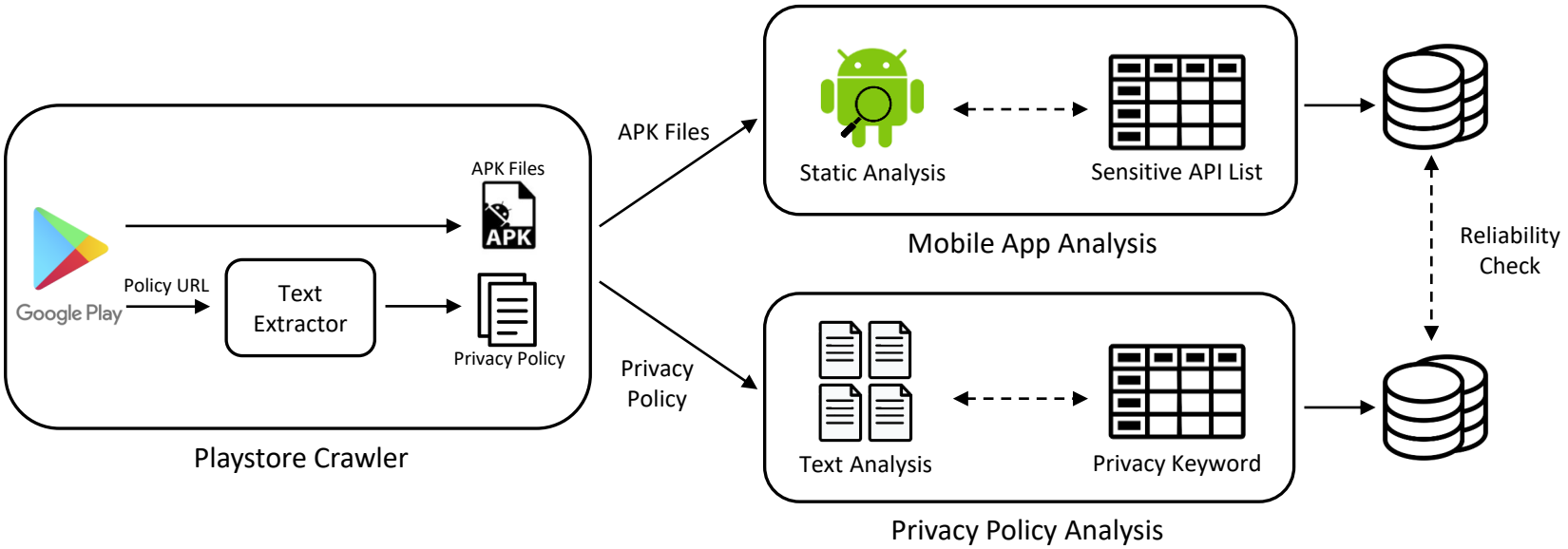
- To ensure privacy transparency while using the app, we
  - Perform an mobile app analysis to check which data the app has access to
  - Perform a policy analysis to check the app practices described by the developers
  - Compare the results to check the reliability



System Design

System Design

- Overview



Privacy Category

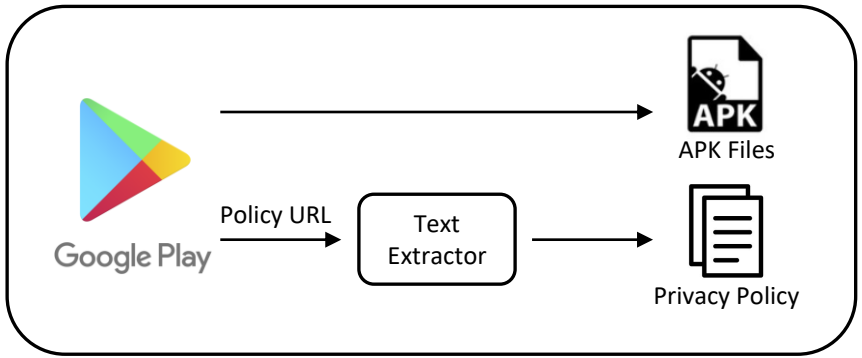
- We categorize personal data for analysis
  - The categories are based on Google User Data Policy
- For app analysis, we check the API lists that collect each personal data
  - The API lists are based on Android Documentation
- For policy analysis, we make a keyword list corresponding to each category

Category	Sub Category
Contact	Email
	Phone Number
Unique Identifier (ID)	Cookie
	Android ID
	IMEI
	IMSI
	MAC
	Mobile Carrier
	SIM Serial
	SSID and BSSID
Location	Cell Tower
	GPS and WiFi

Playstore Crawler

- The playstore crawler downloads app's APK files and metadata from app store
  - We use open source crawler for collecting initial dataset

- The metadata contains app title, package name, policy URL, etc
  - Crawler stores this metadata on MongoDB in Json format



Playstore Crawler

Mobile App Analysis

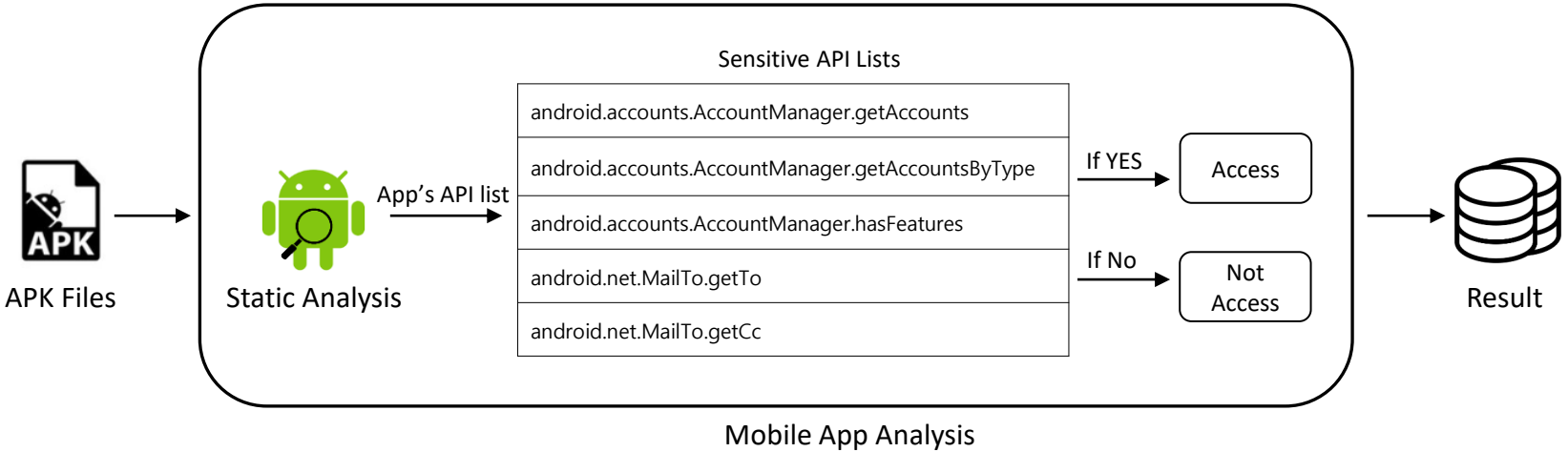
- We check the Sensitive API lists that collect each personal data
  - The API lists are based on Android Documentation

< Table : Example of Sensitive API Lists >

Category	Sensitive API
IMEI	android.telephony.TelephonyManager.getDeviceId
	android.telephony.TelephonyManager.getImei
GPS and WiFi	FusedLocationProviderClient.getLastLocation
	android.location.LocationManager.requestLocationUpdates
	android.location.LocationManager.requestSingleUpdate
	android.location.LocationManager.getLastKnownLocation

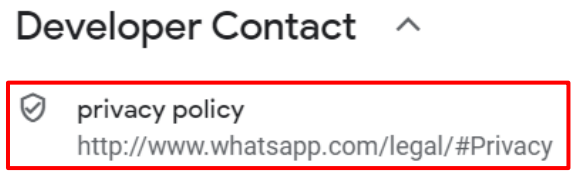
Mobile App Analysis

- The system analyzes whether the apps have APIs that access personal data
  - It conduct the analysis by comparing the app's API and Sensitive API Lists
  - We use Androguard for static analysis

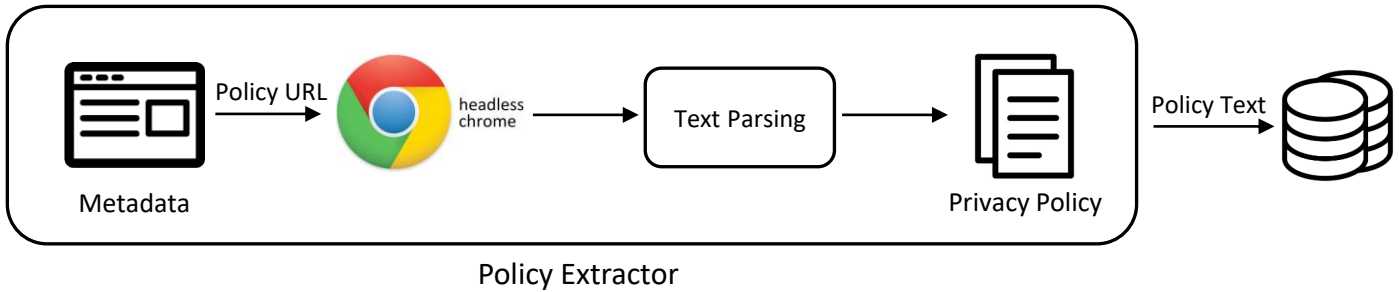


Privacy Policy Analysis

- We extract privacy policy text from policy URL



- We create a text extractor to handle errors while extracting privacy policy
  - First, the extractor renders the policy URL by chrome headless browser
  - Next, it uses Readability.js to parse the main text of the page
  - If Readability.js is not working, make an exception (E.g. different policy URL format)



Privacy Policy Analysis

- We select 50 apps to effectiveness of privacy keyword
  - We check correctness of policy analysis results in person

		Prediction (Policy Analysis Results)	
		True	**False**
Actual Result	**True**	True Positive (TP)	False Negative (FN)
	False	False Positive (FP)	True Negative (TN)

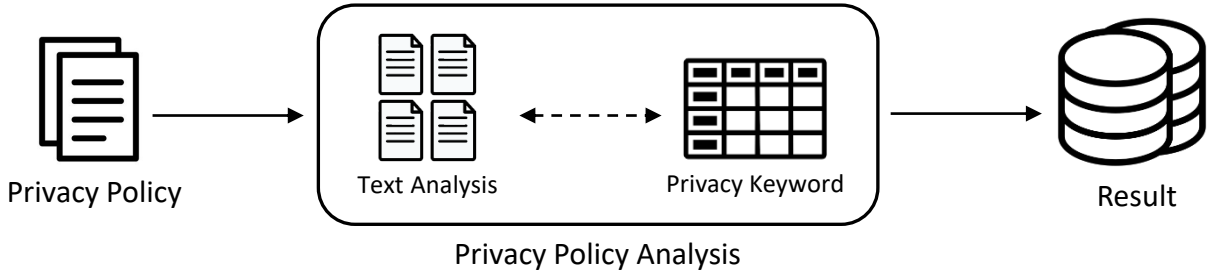
Precision	Recall	F1 score
0.814	0.778	0.796

$$precision = TP/(TP + FP)$$
$$recall = TP/(TP + FN)$$

Privacy Policy Analysis

- The system classifies the privacy policy to identify the specific policy text that describe a certain practice
  - The system analyzes whether the policy text describes the use of personal data

- The system conducts policy analysis to identify if the policy text has contents about the personal data



Privacy Policy Analysis: Result

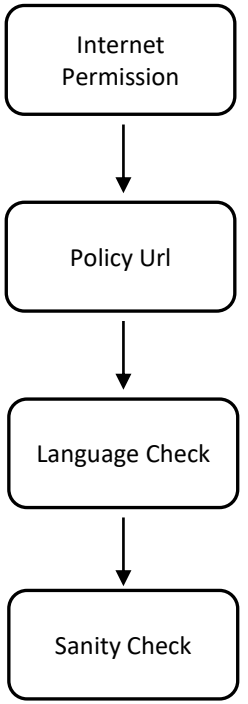
- The analysis results are recorded for each personal data

App Name	Personal Data Category
Youtube	Contact, Email, Phone Number, Identifier, Cookie, Device ID, Location, GPS and WiFi
Whatsapp	Contact, Email, Phone Number, Identifier, Cookie, Device ID, Location
Nexflix	Contact, Phone Number, Identifier, Cookie, Device ID, IMEI
Twitter	Contact, Email, Phone Number, Identifier, Cookie, Device ID, Location
Tiktok	Contact, Email, Phone Number, Identifier, Cookie, Device ID, IMEI, MAC, Location, GPS and WiFi

Result

Preprocessing Dataset

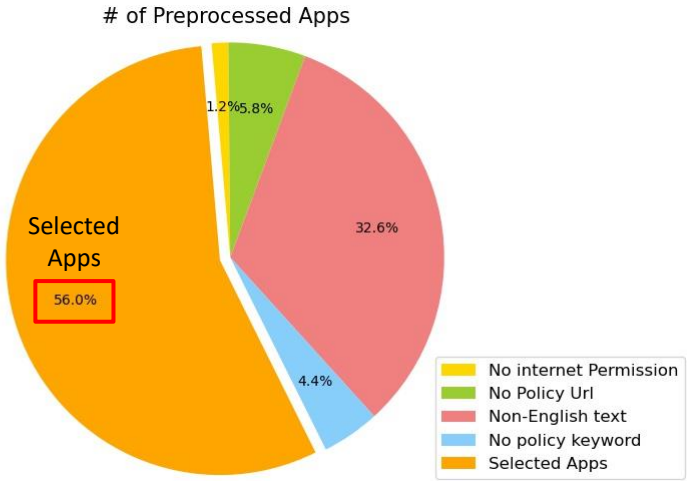
- We preprocess the dataset to select the app for analysis
- The dataset is preprocessed under 4 conditions
  - Condition 1: Internet permission
  - Condition 2: Policy URL
  - Condition 3: Language check (English)
  - Condition 4: Sanity check
- We conduct policy and app analysis on selected apps



Dataset

- The playstore crawler collected over 13K android apps' APK files and metadata

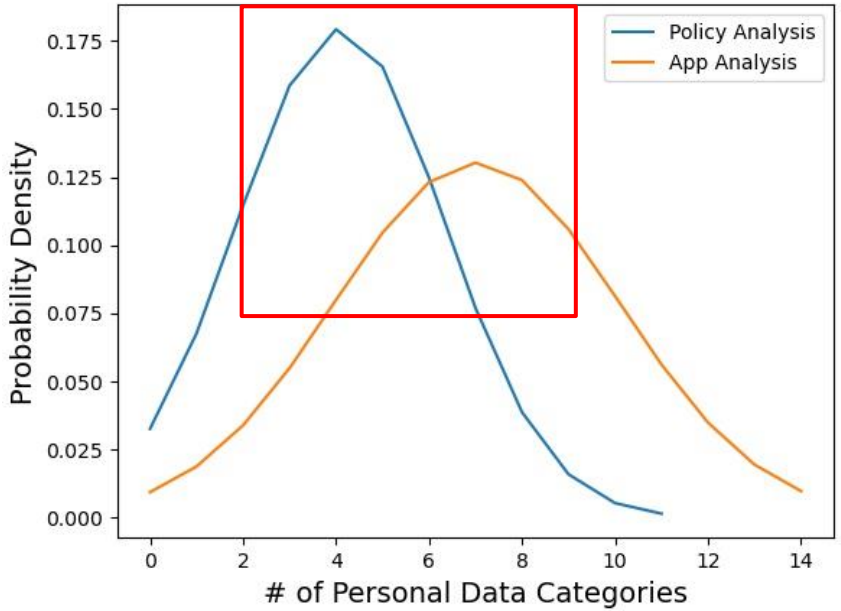
- The system preprocessed the collected apps based on their metadata
  - Internet permission (13,223 → 13,058)
  - Policy Url (13,058 → 12,286)
  - English text (12,286 → 7,981)
  - Policy keyword (7,981 → 7,401)



- The system conducted policy and app analysis on 7.4K apps

Number of Personal Data Categories

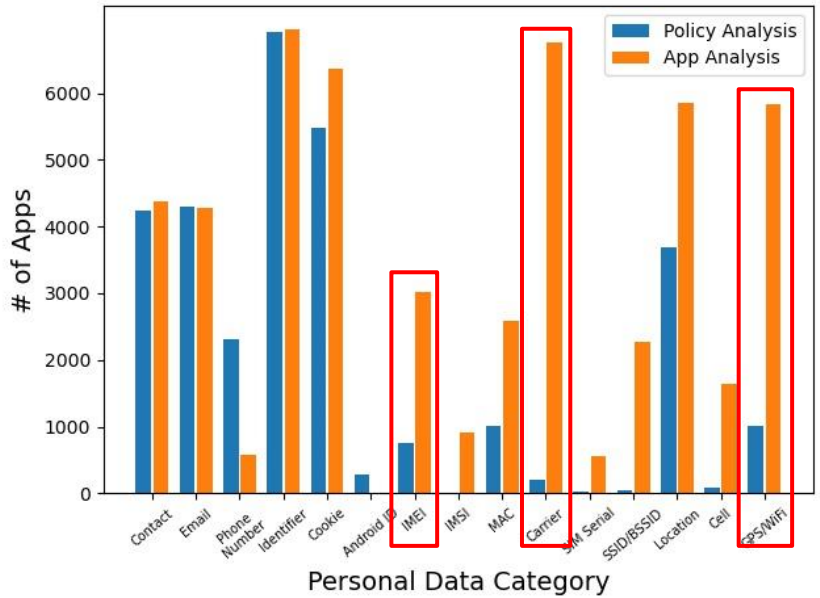
- App analysis results include more personal data categories



Number of Personal Data Categories by Policy and App Analysis

Number of Apps for Each Category

- Some personal data categories make a big difference

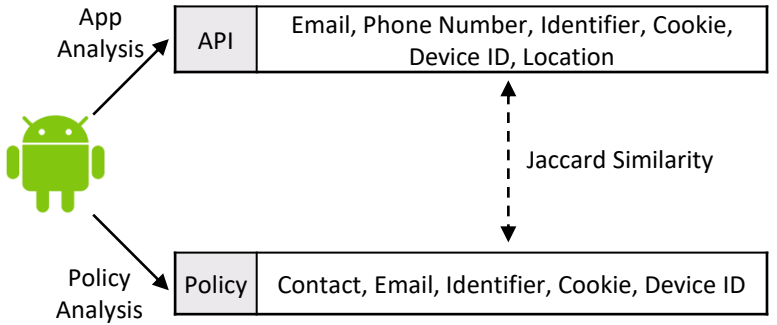


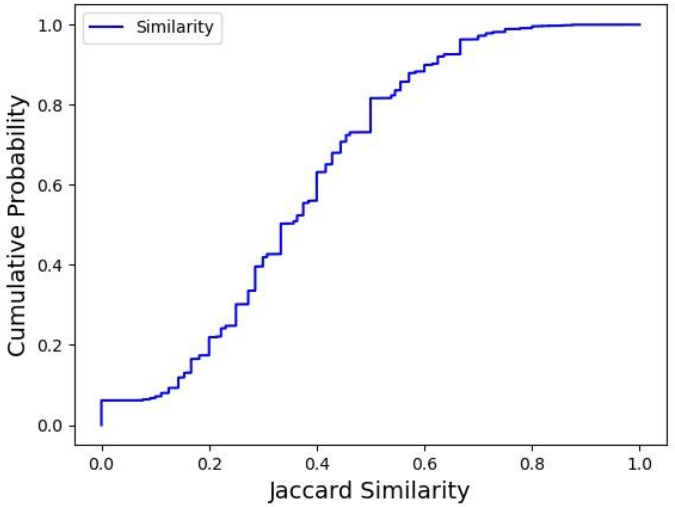
Number of Apps for Each Category

Jaccard Similarity

- Jaccard similarity computes the similarity of policy and app practice

Jaccard Similarity: $J(A,B) = \frac{A \cap B}{A \cup B} = \frac{\text{App Analysis} \cap \text{Policy Analysis}}{\text{App Analysis} \cup \text{Policy Analysis}}$

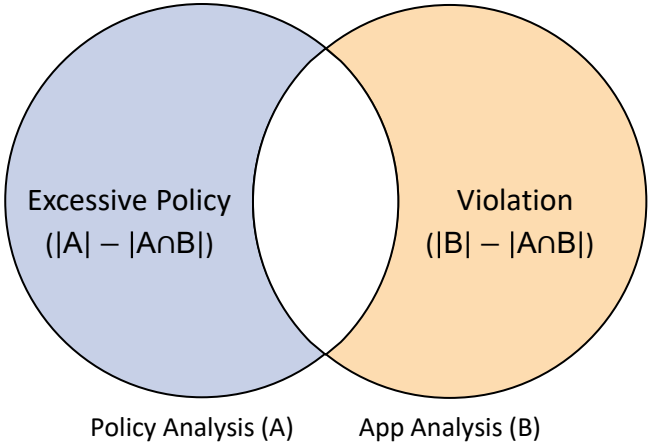




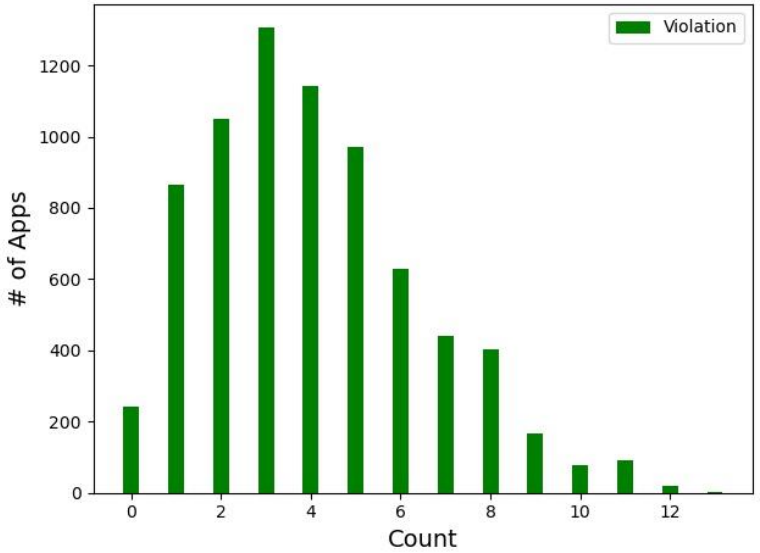
Similarity between Policy and App Practice

Excessive Policy and Violation

- We defined Excessive Policy and Violation for checking reliability

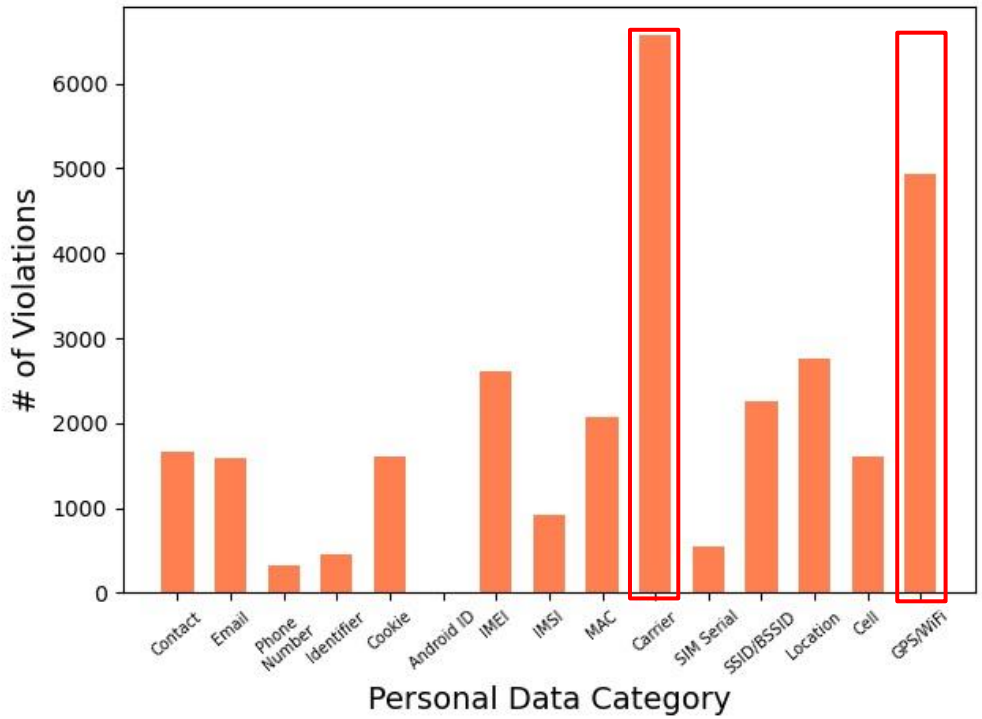


Definition of Excessive Policy and Violation



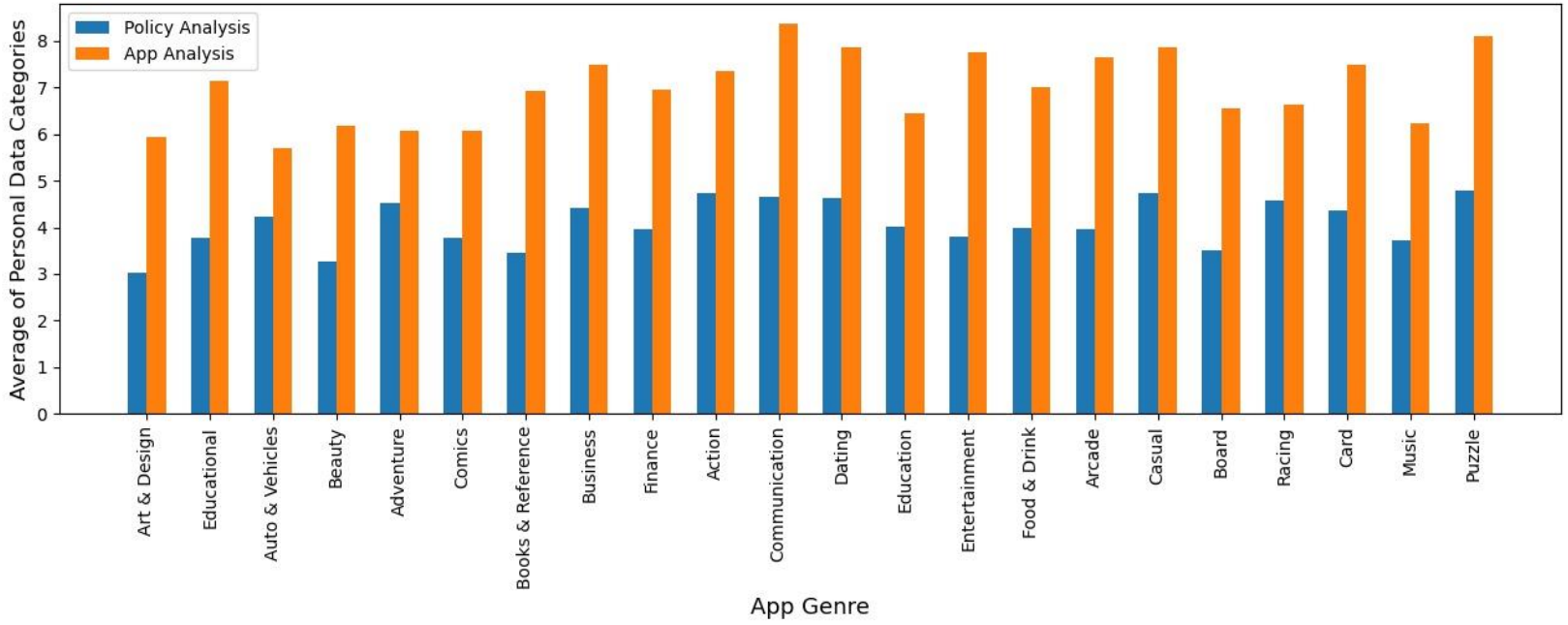
Number of Apps by Violation Count

Violation by Category



Number of Violations by Personal Data Category

Average of Personal Data Categories by Genre

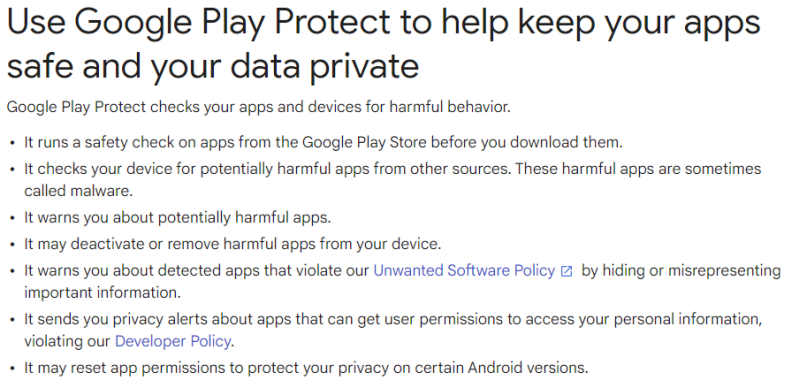


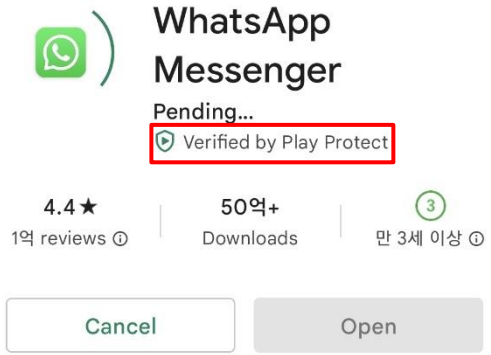
Average of Personal Data Categories by Genre

Conclusion

- Privacy policy is the only way to know how the app collect user data
  - It may be an inconsistency in app practices and privacy policy

- Google use Play Protect to check apps and devices for harmful behavior
  - It is hard to check all the app's practices





Conclusion

- We analyzed the app practices and privacy policy to check the reliability
  - Mobile app analysis shows whether the apps have APIs that access personal data
  - Privacy policy analysis identify the specific policy text that describe a certain practice
  - We compared these result to check if privacy policies are reliable

- Results show that apps can access more personal data than expected
  - App has more violation than excessive policy
  - We need more solutions to enable users to check the reliability

Thank you

Q&A

Appendix

Privacy Table: Policy Analysis

Category	Keyword	Sub Category	Keyword
Contact	· contact information · account	Email	· email address · e-mail address · email id
		Phone Number	· phone number · telephone number
Unique Identifier (ID)	· personal information · device id · unique id · phone status	Cookie	· cookie
		Android Id	· android id
		IMEI	· international mobile device identification code · IMEI
		IMSI	· IMSI · subscriber ID
		MAC	· MAC · network card address · Media Access Control
		Mobile Carrier	· mobile carrier · mobile network operator · MNO · sim operator · wireless service provider
		SIM Serial	· sim serial · sim card
		SSID BSSID	· wifi router · wi-fi router · SSID · BSSID
Location	· location	Cell Tower	· cell tower · cellular tower · cell information
		GPS and WiFi	· network state · GPS · wifi · wi-fi · geolocation

Privacy Table: Example

Category	Keyword	Sub Category	Keyword	API
Unique Identifier (ID)	· personal information · device id · unique id · phone status	IMEI	· international mobile device identification code · IMEI	android.telephony.TelephonyManager.getDeviceId
				android.telephony.TelephonyManager.getImei
		IMSI	· IMSI · subscriber ID	android.telephony.TelephonyManager.getSubscriberId
		SIM Serial	· sim serial · sim card	android.telephony.TelephonyManager.getSimSerialNumber
		SSID BSSID	· wifi router · wi-fi router · SSID · BSSID	android.net.wifi.WifiManager.getConfiguredNetworks
				android.net.wifi.WifiInfo.getBSSID
				android.net.wifi.WifiInfo.getSSID

Privacy Table: App Analysis

Category	Sub Category	API
Contact	Email	android.accounts.AccountManager.getAccounts
		android.accounts.AccountManager.getAccountsByType
		android.accounts.AccountManager.getAccountsByTypeAndFeatures
		android.accounts.AccountManager.getAccountsByTypeForPackage
	Phone Number	android.telephony.TelephonyManager.getLine1Number
Unique Identifier (ID)	Cookie	android.webkit.CookieManager.getInstance
	Android Id	android.provider.Settings.Secure.getString
	IMEI	android.telephony.TelephonyManager.getDeviceId
		android.telephony.TelephonyManager.getImei
	IMSI	android.telephony.TelephonyManager.getSubscriberId
	MAC	android.net.wifi.WifiInfo.getMacAddress
	Mobile Carrier	android.telephony.TelephonyManager.getNetworkOperator
		android.telephony.TelephonyManager.getNetworkOperatorName
		android.telephony.TelephonyManager.getSimOperator
		android.telephony.TelephonyManager.getSimOperatorName
	SIM Serial	android.telephony.TelephonyManager.getSimSerialNumber
	SSID BSSID	android.net.wifi.WifiManager.getConfiguredNetworks
		android.net.wifi.WifiInfo.getBSSID
		android.net.wifi.WifiInfo.getSSID
Location	Cell Tower	FusedLocationProviderClient.getLastLocation
		android.location.LocationManager.requestLocationUpdates
		android.location.LocationManager.requestSingleUpdate
		android.location.LocationManager.getLastKnownLocation
		android.telephony.gsm.GsmCellLocation.getCid
		android.telephony.gsm.GsmCellLocation.getLac
		android.telephony.TelephonyManager.getCellLocation
		android.telephony.TelephonyManager.getAllCellInfo
	GPS and WiFi	FusedLocationProviderClient.getLastLocation
		android.location.LocationManager.requestLocationUpdates
		android.location.LocationManager.requestSingleUpdate
		android.location.LocationManager.getLastKnownLocation

Related Work: Privacy Policy Analysis

- Privacy policy corpus creation
  - Wilson et al. (2016) create a privacy policy corpus (OPP-115) of 115 web privacy policies with crowdsourcing
  - Lebanoff et al. (2018) create a corpus for privacy policies for vague words prediction
  - Zimmeck et al. (2019) create an app privacy policy corpus (APP-350) for App executable and privacy policy compliance check

- Automatic privacy policy analysis
  - Ramanath et al. (2014), Liu et al. (2018) focus on the structure of privacy by identifying policy sections relating to different topics
  - Sathyendra et al. (2017) provide labels on opt-out choices similar consumer choice options on websites
  - Libert (2018) finds that the names of third parties are usually not explicitly disclosed in website privacy policies

Related Work: Mobile App Analysis

- Static Analysis
  - Mutchler et al (2015) analyze Android web apps and find that 28% of those have at least one vulnerability
  - Story et al. (2018) study the metadata of apps on the Play Store and find that many apps lack privacy policies, even when developers describe the data collection
  - Reyes et al. (2018) reveal that many Android apps collect persistent device identifiers to track users, which is not allowed for advertising purposes

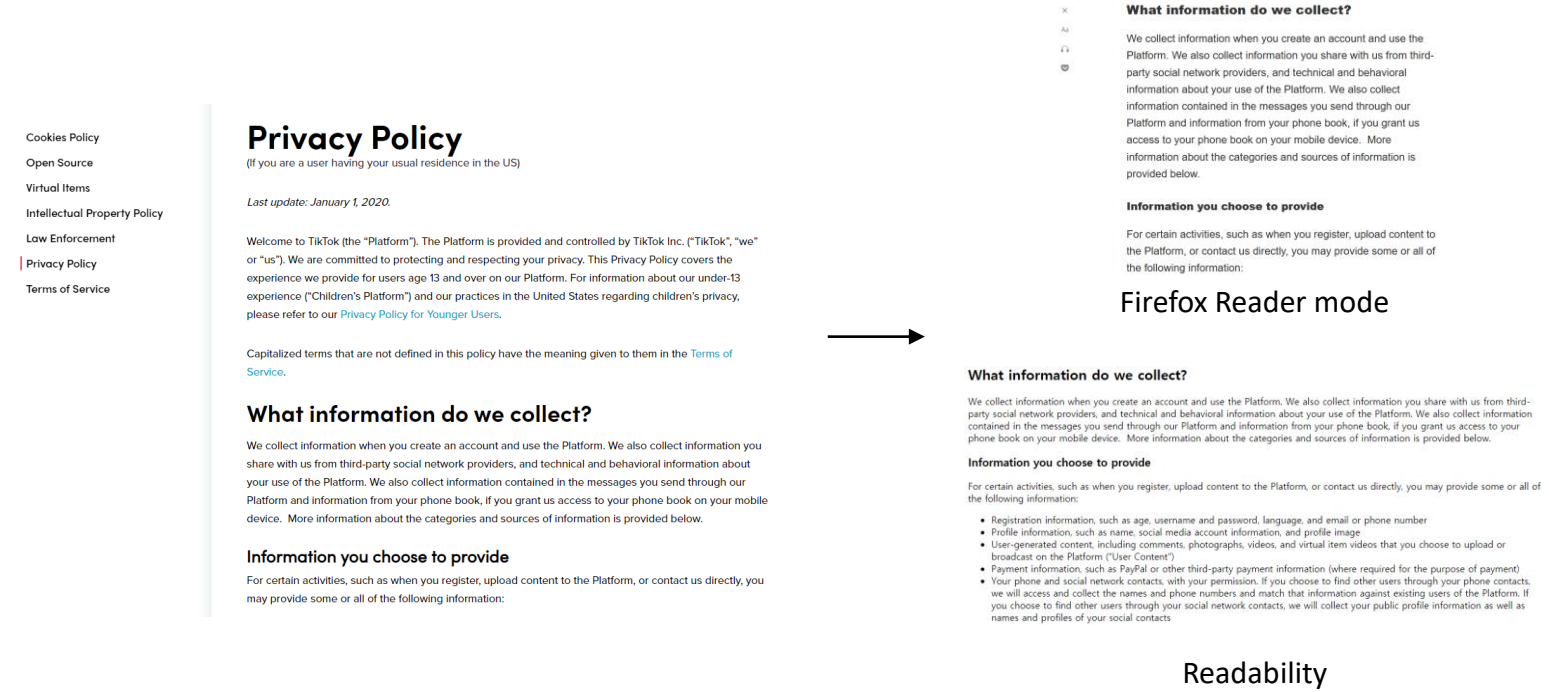
- Dynamic Analysis
  - Abbas et al. (2015) develop Haystack (Lumen app) to monitor traffic from apps
  - Ren et al.(2018) study privacy leak using Lumen and UI monkey generator

Work

- We built an automated system that analyzes the privacy policy and app practices to check the consistency
  - We created privacy table to analyze the privacy policies and android methods regarding sensitive data
- The system crawled play store to collect APK files and policy text
- We analyzed privacy policy text to identify which data is informed to be collected
- We analyzed app source code to identify whether the app has sensitive API

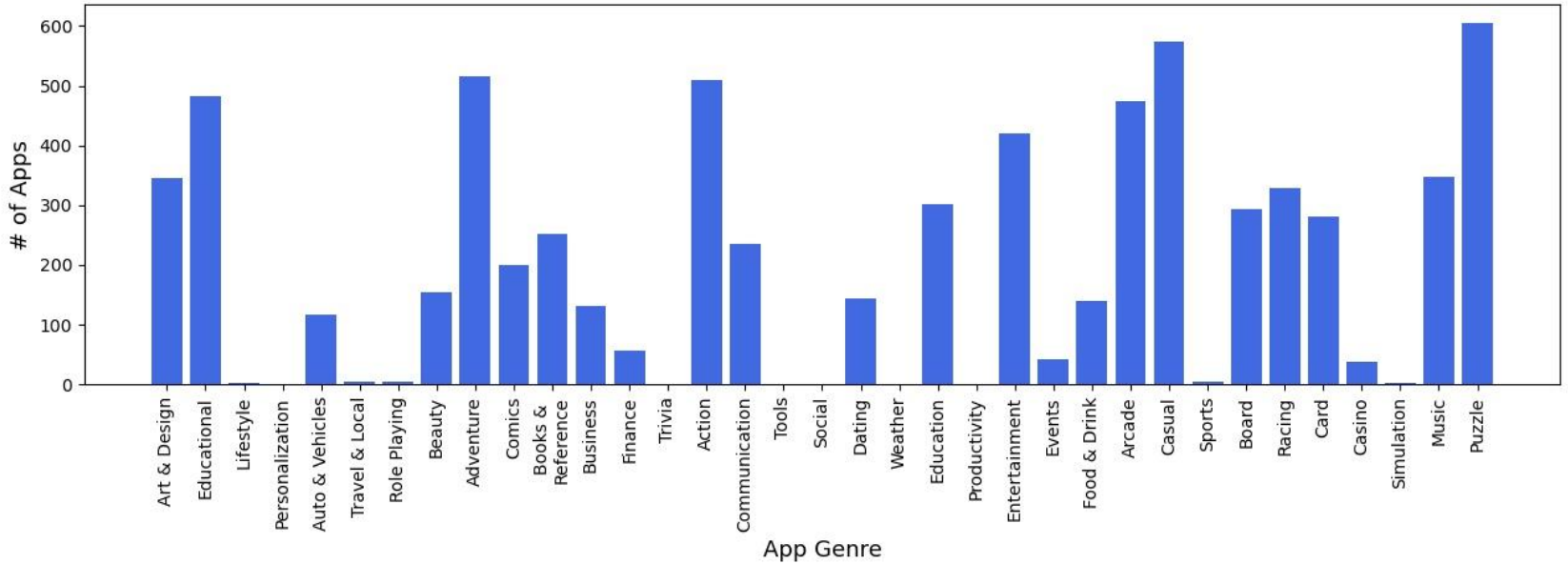
Readability.js

- Node.js library that provides Firefox Reader Mode



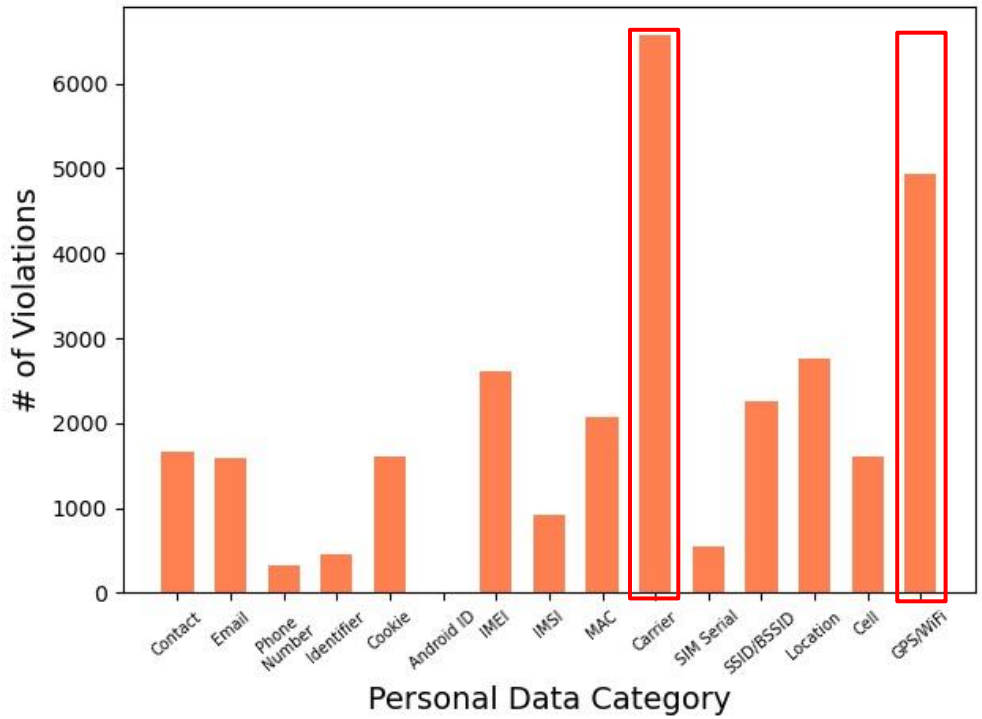
Number of Apps by genre

- Fewer than 100 apps were collected in some genres
  - We excluded the genres from the analysis to obtain a more accurate result



Number of Apps by genre

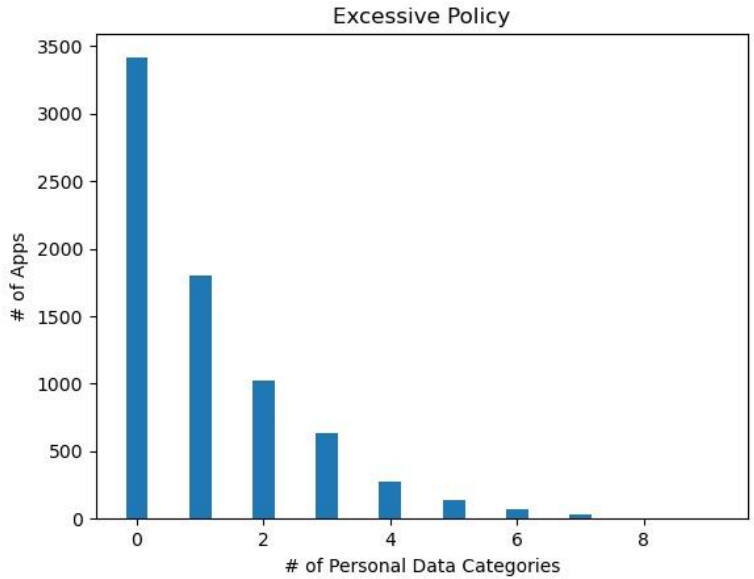
Violation by Category

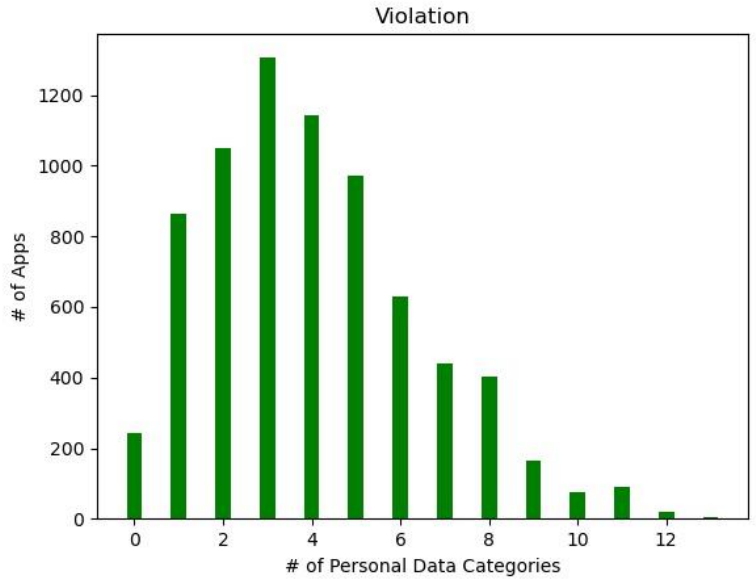


Number of Violations by Personal Data Category

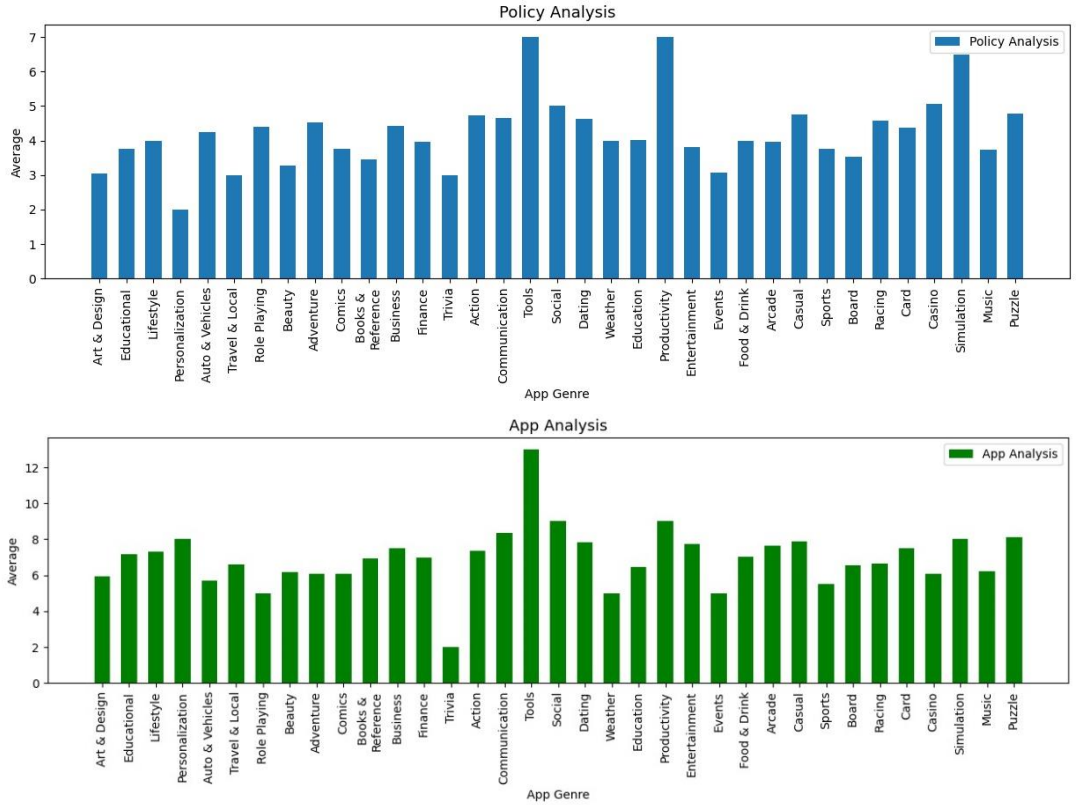
Excessive Policy and Violation Count

- Number of Apps by Excessive Policy and Violation Count





Average of Personal Data Categories by Genre



App Analyzer

- The system analyzes whether the apps have APIs that access personal data
  - It conduct the analysis by comparing the app's API and privacy table
  - We use Androguard for static analysis

- After the analysis, the system store the API list to the database