An Empirical Study of Web Resource Manipulation in Real-world Mobile Applications

Xiaohan Zhang, Yuan Zhang, Qianqian Mo, Hao Xia, Zhemin Yang, Min Yang

XiaoFeng Wang, Long Lu, and Haixin Duan

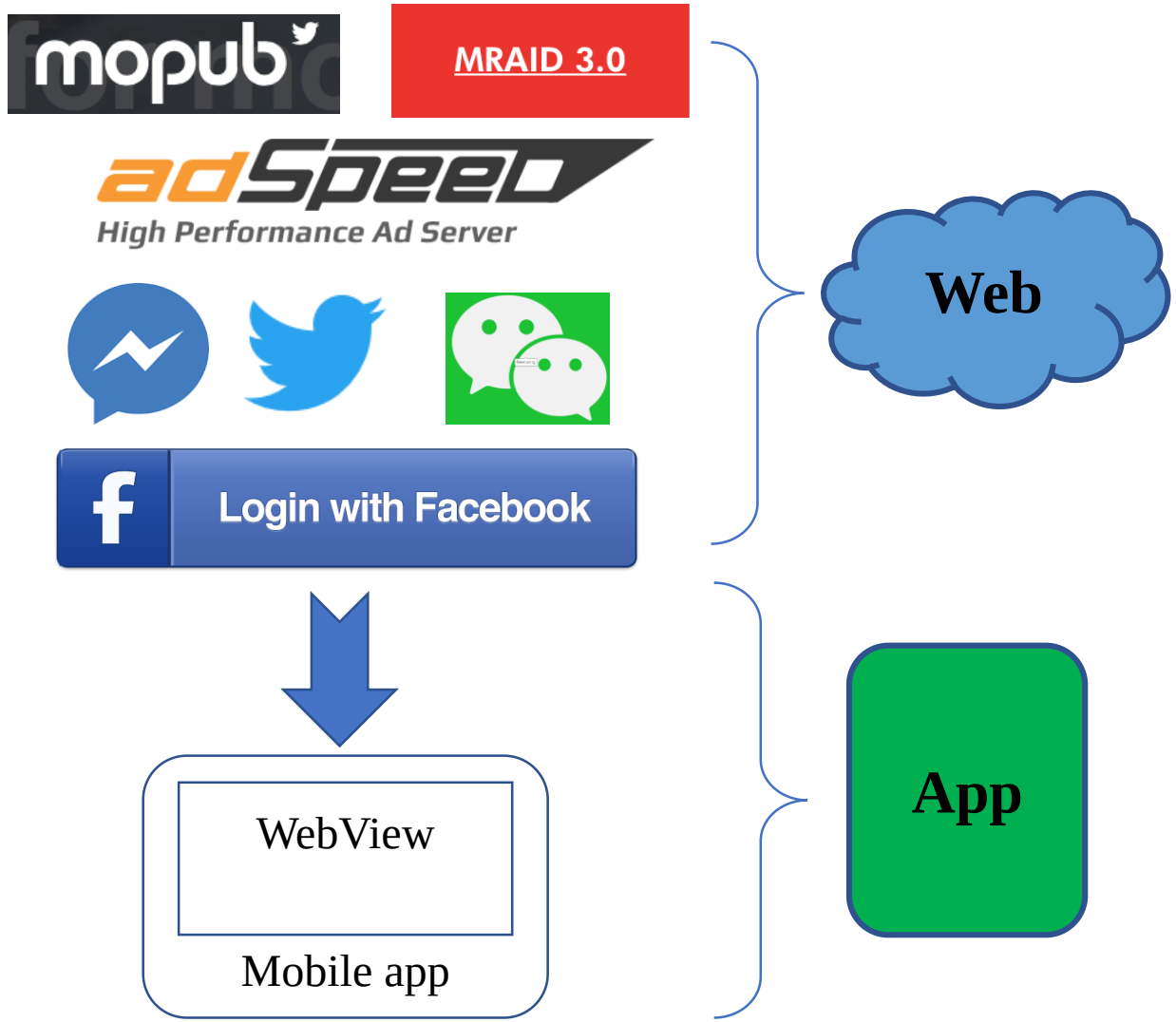
INDIANA UNIVERSITY

Northeastern University
College of Computer and Information Science

Background

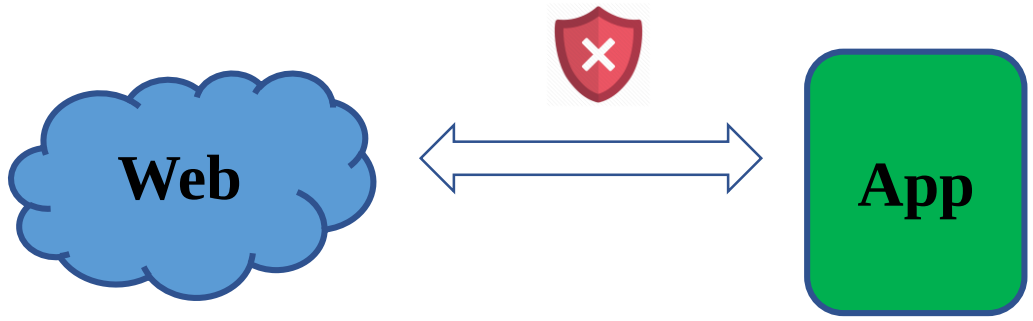
- Mobile apps are integrating more and more Web services
  - advertising
  - social sharing
  - even authentication and authorization

- Most of Web-App integrations are through light-weight **in-app** Web browsers, called WebViews
  - Android: WebView
  - iOS: UIWebView/WKWebView



Web-App Integration Security Risks

- Security risks to both sides
  - Web-to-App attacks
  - App-to-Web attacks



Web-App Integration Security Risks

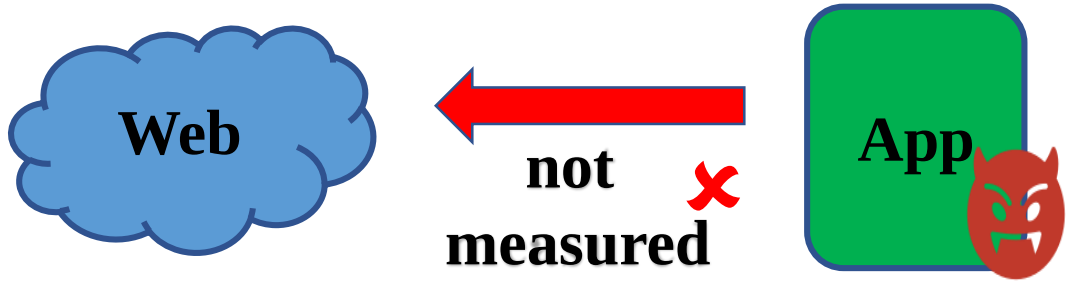
- Security risks on both sides
  - Web-to-App attack
  - App-to-Web attack

- **Web-to-App attacks**
  - where unauthorized Web code access sensitive functions of the host apps
- Existing works
  - attacks [luo et al. ACSAC'11], [Sooel et.al, NDSS' 16], [OSV-Hunter, S&P '18]
  - detections [BridgeScope, RAID'17]
  - defenses [NoFrak, NDSS'14], [Draco, CCS'16]

Web-App Integration Security Risks

- Security risks on both sides
  - Web-to-App attacks
  - App-to-Web attacks

- **App-to-Web attacks**
  - where the host apps manipulate sensitive resources of the Web
- Existing works
  - partially mentioned in theory [luo et al. ACSAC'11], [Eric et al. CCS'14]
  - no real-world cases



Open Questions:

1. How Web resources are manipulated by real-world apps?

2. Are there any real-world App-to-Web attacks?

Web Resource Manipulation APIs

- Both Android and iOS provide a handful of APIs for host apps to manipulate the Web resources

Manipulated Web Resources	Android WebView	iOS UIWebView	iOS WKWebView
Local Storage	CookieManager	NSHTTPCookieStorage	WKWebsiteDataStorage
Web Content	loadUrl, evaulateJavascript	stringByEvaluatingJavascript FromString	evaluateJavascript
Web Address	onPageFinished, shouldOverrideUrlLoading	\	\
Network Traffic	shouldInteceptRequest	shouldStartLoadWithRequest	decidePolicyForNavigationAction, decidePolicyForNavigationResponse

Examples:

1. obtain cookies using *CookieManager.getCookie*
2. intercept network traffic to get user credentials using *shouldInterceptRequest*

Is it secure?

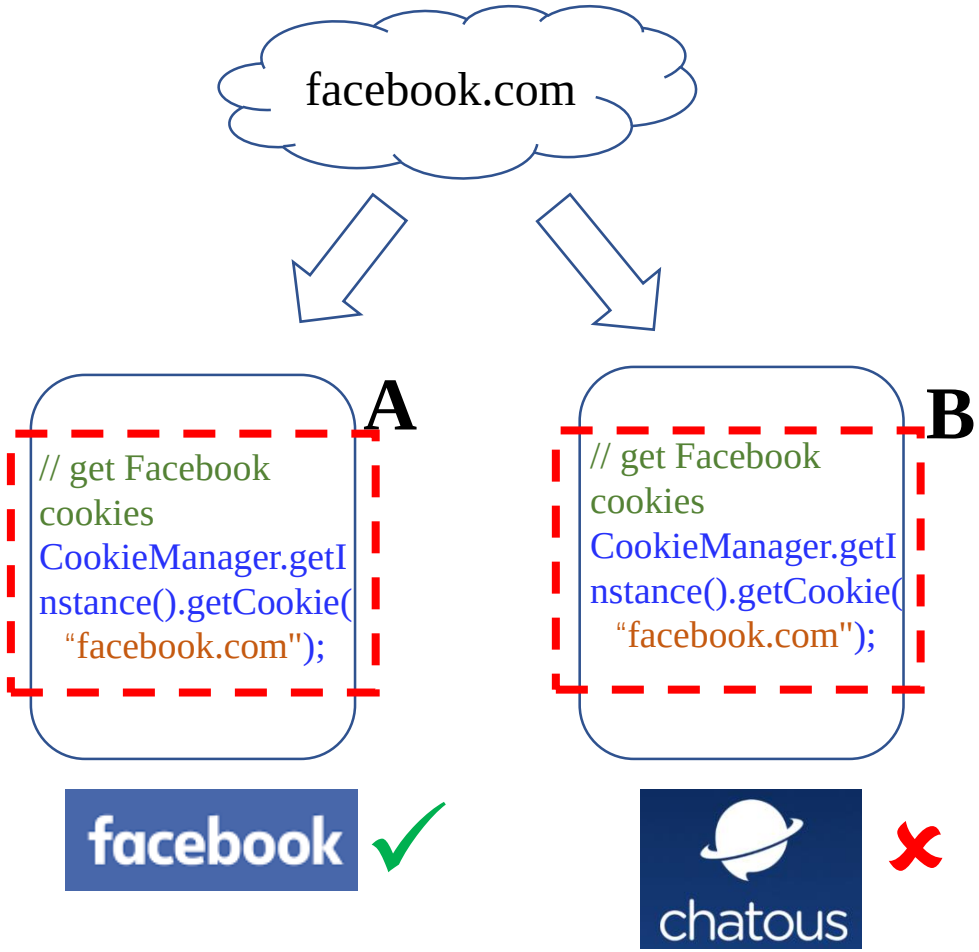
Motivating Example

The Website *facebook.com* is loaded into WebViews of two apps

- both apps use *CookieManager.getCookie* to get cookies of *facebook.com*

App A : Facebook's official app

App B: Chatous, a third-party app



Observation: it is risky when security principals are crossed!

Definitions

- Two security principals involved
  - **Web Principal,** the manipulated Web resources, P_w
  - **App Principal,** the manipulating code, P_A

- Cross Principal Manipulation (XPM)

$$P_w \neq P_A$$

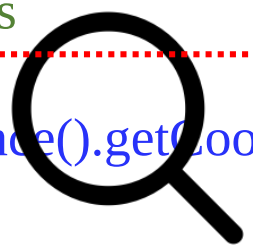
Target: to measure XPMs in real-world apps

Methodology

- Finding XPMs in real-world apps

1. locate all manipulations 2. identify P_A and P_W 3. determine $P_A = P_W$?

```
package com.chatous.chatous.managers;
…
if (CookieManager.getInstance().getCookie(   “https://facebook.com") != null)
{
    // get Facebook cookies
    cookies =
CookieManager.getInstance().getCookie(   “https://facebook.com");
    // store these cookies
    BasicCookieStore cookieStore = new BasicCookieStore();
    cookieStore.addCookie(cookies);
    …
    // abuse these cookies to collect user privacy information.
    …
```



$P_A \neq P_W$ → XPM

Non-trivial

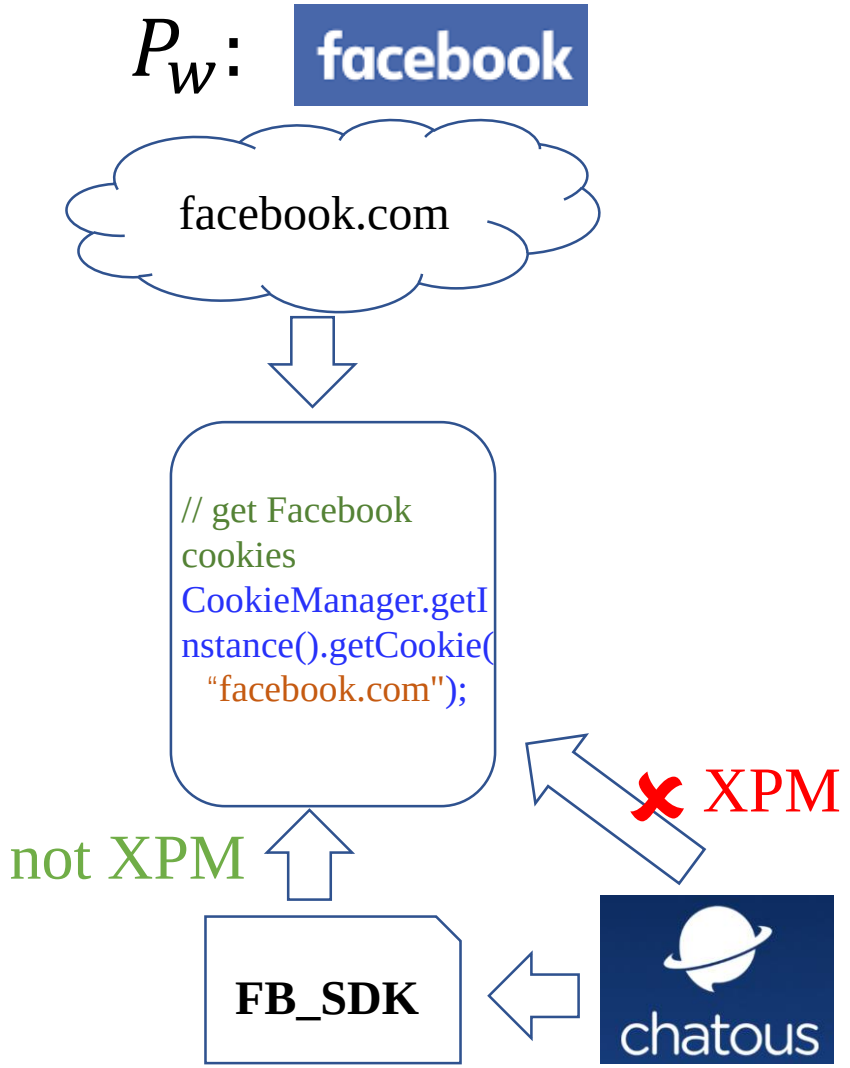
Identify App Principals

Challenge 1: multiple security principals exist in the app

- the host app itself
- several third-party libraries

- **Solution**: identify third-party libraries
  - $\boldsymbol{P_A}$ of third-party library: library name
  - $\boldsymbol{P_A}$ of the host app: host app's meta-info

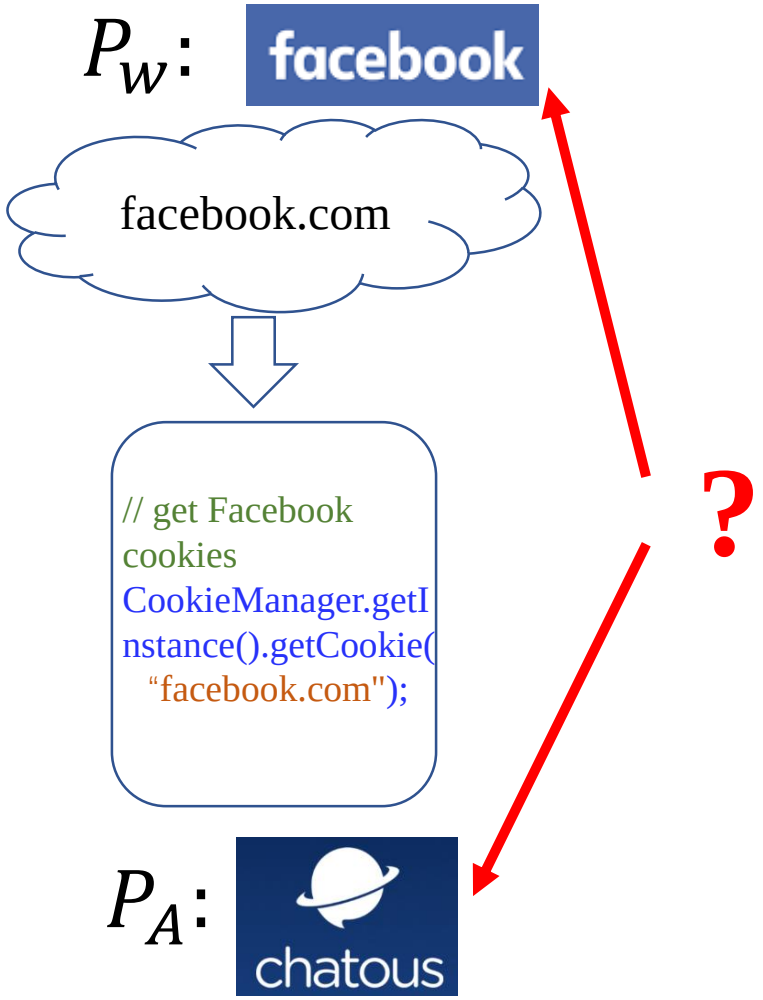
- library identification algorithm
  - Merkle-tree based code signature
  - please refer to our paper for more details



Determine $P_w = P_A$?

Challenge 2: semantic gaps between P_w and P_A

- “chatous” and “facebook”
- “google” and “youtube”
- abbreviation: “fb” and “facebook”

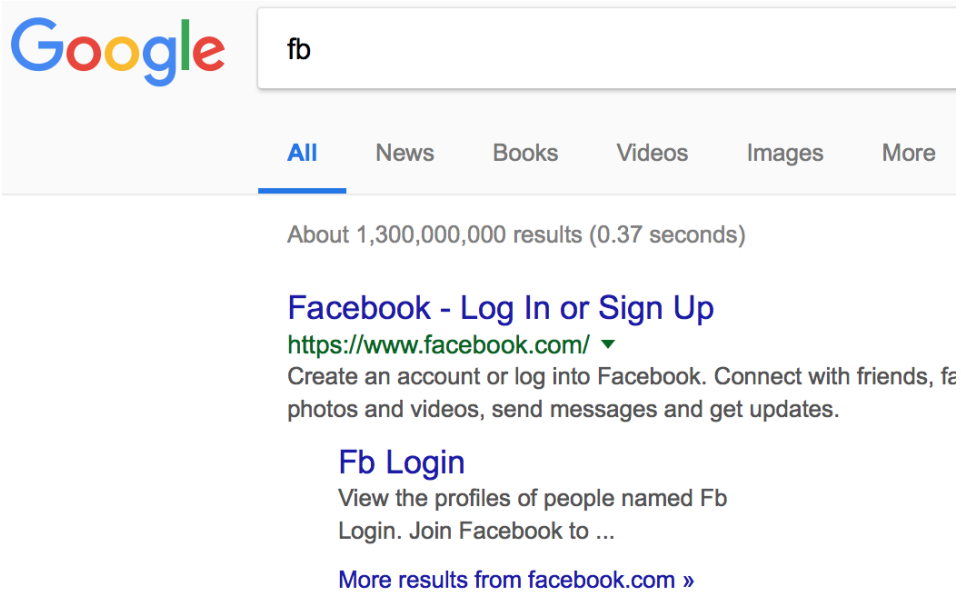


Determine $P_w = P_A$?

Challenge 2: semantic gaps between P_w and P_A

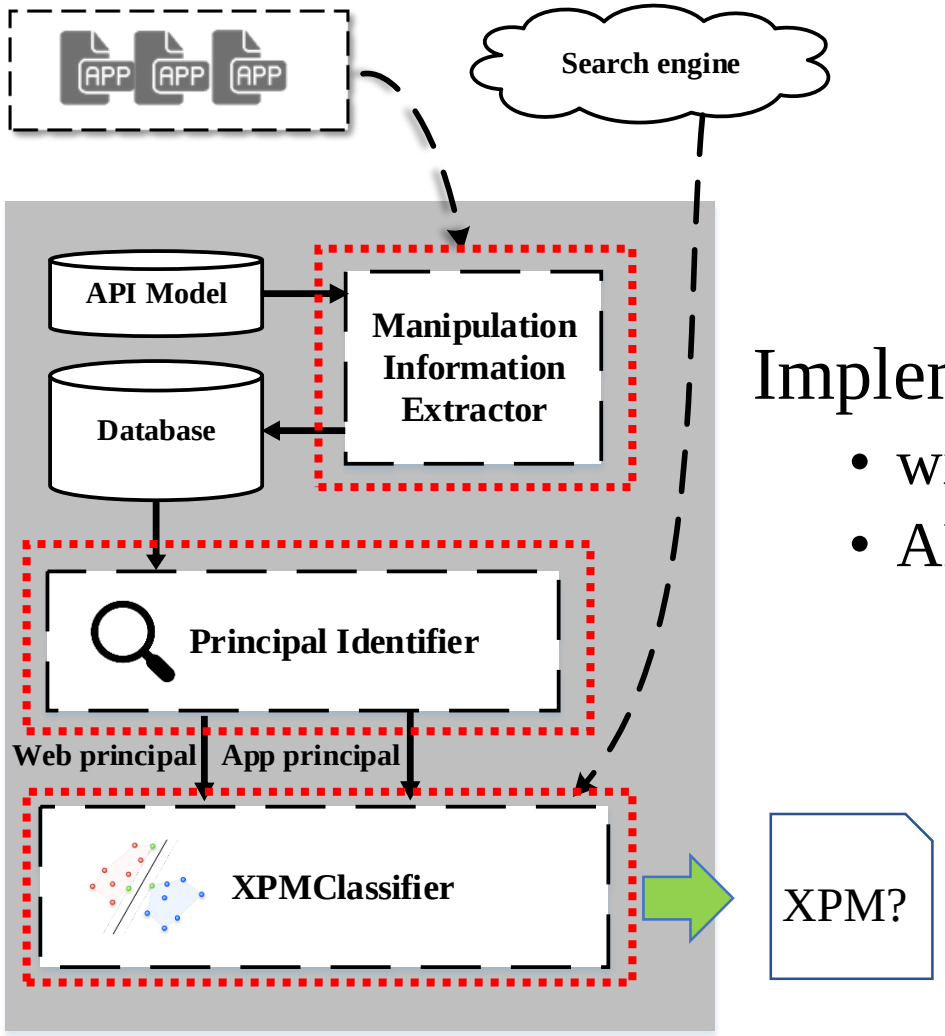
- "chatous" and "facebook"
- "google" and "youtube"
- abbreviation: "fb" and "facebook"

- **solution**: ask search engine
  - e.g. "facebook" and "fb" have more than 80% similarity in google search result
- searching-based classifier
  - normalize search results into W *and* A using bag-of-words model
  - similarity distances between these two vectors



$$isXPM(P_w, P_a) := sim\_distance(P_w, P_a) \geq \theta$$

XPMChecker Design & Implementation



XPMChecker Overview

Implementation is based on *Soot* and *FlowDroid*

- with customized ICFG
- API-specific data flow analysis

(please refer to our paper for more technical details)

XPMChecker Evaluation

- Dataset
  - **84,712** apps from Google Play during Jul 2017, with at least 5,000 installations across 48 categories.

- Performance
  - **95.3%** of all apps (80,694/84,712) are successfully analyzed
  - 233 hours with 9 processes, **10 seconds/app**.
    - CentOS 7.4 64-bit server, 64 CPU cores (2GHz), 188 GB memory
    - 9 processes, 20 minutes timeout
- Effectiveness
  - with 200 manually labeled ground truth
  - **98.9%** precision and **97.9%** recall $(\theta = 0.3134)$

Finding: XPM Prevalence

- **XPMs are very popular in real-world apps**
  - **4.8%** (3,858/80,694) of all apps contain XPMs

	# of Apps (% in all apps)	# of manipulations
Apps that manipulate Web resources	13,599 (16.9%)	29,448
Apps with XPMs	3,858 (4.8%)	**14,476 (49.2%)**

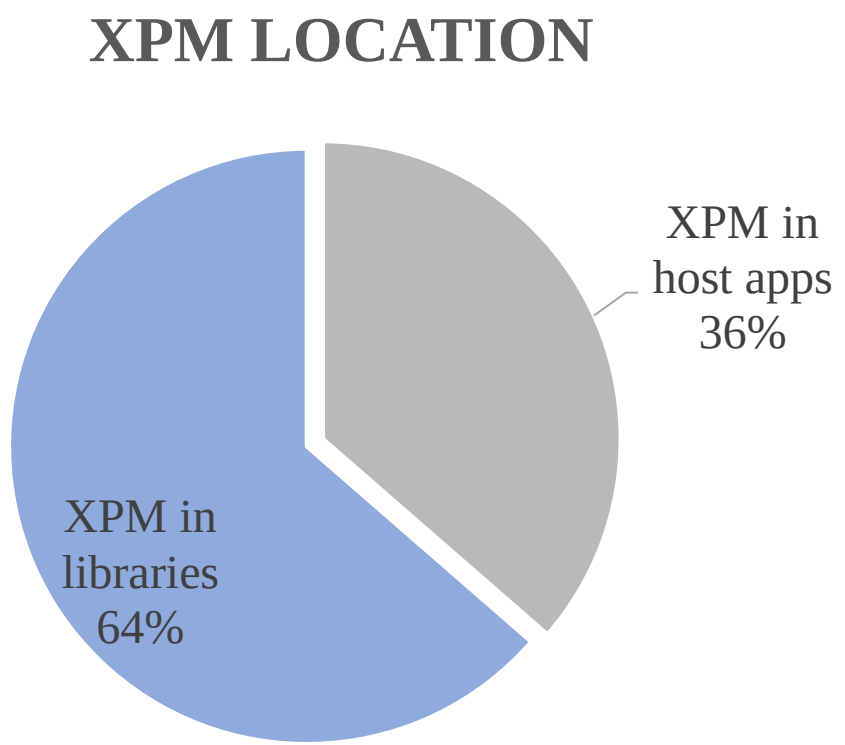
  - **49.2**% (14,776/29,448) of all Web resource manipulations are cross-principal.

Finding: XPM Location

- **A large part of XPMs are from libraries.**
  - 63.6% of XPMs originate from 88 libraries in our dataset

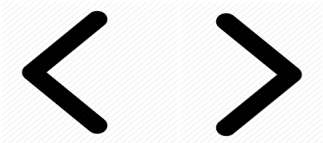
- **Reflections** on current defensive work
  - works that consider the app as a single principal is not fine-grained enough nor accurate

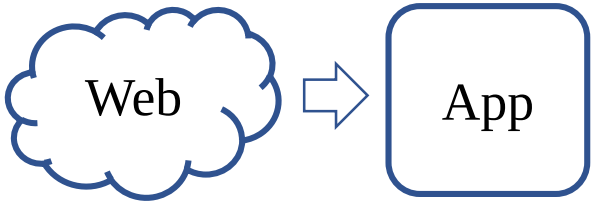
    [WIREFRAME, AsiaCCS'17]



Finding: XPM Intents

- **More than 90% XPMs provide normal utilities**
  - Inject JS to customize Web services to improve user experience
    - add navigation controls
    - customize Google Cloud Print
  - Monitor Web addresses to invoke local apps





Malicious XPM Intents

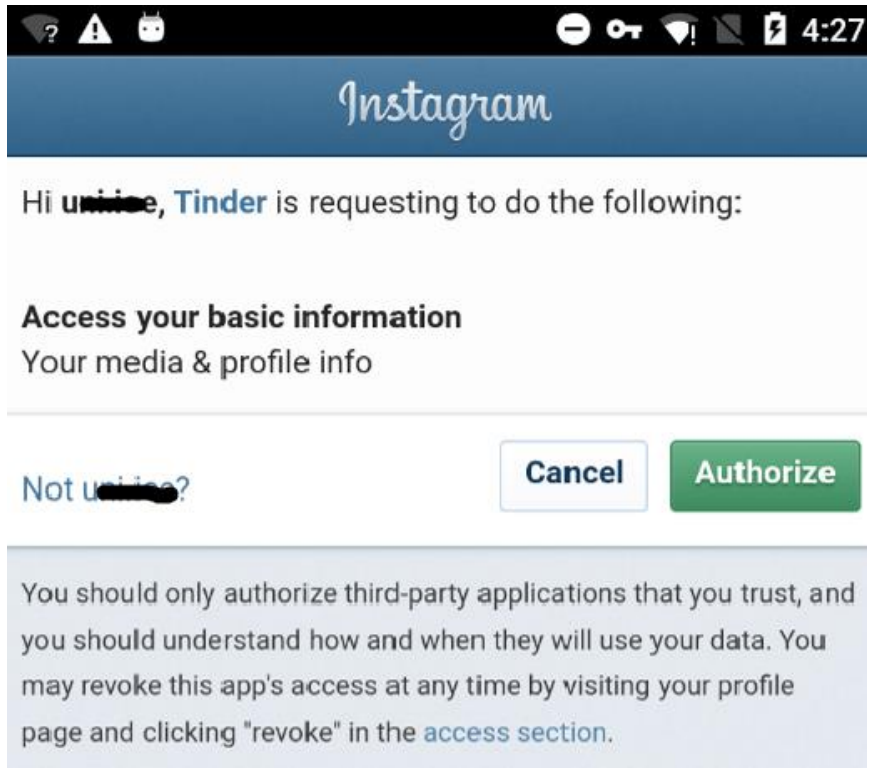
- **Confirm malicious XPMs in real-world for the first time**
  - find 22 malicious XPMs in 21 apps, with up to 130M installations
  - report to Google and the malicious intents are removed
  - 4 iOS apps with such malicious XPMs are also confirmed

- Three categories:

Malicious behavior	# of apps
impersonating legitimate relying party in OAuth	2
stealing user credentials	6
stealing and abusing cookies	14

Case Study 1. Impersonating relying party in OAuth

- App **instaview** impersonates "**Tinder**" in Instagram OAuth
  - a profile tracker for users to see their Instagram visiting statistics
  - 1,000,000-5,000,000 installations




```
package com.instaview.app;
…
public class LoginActivity extends Activity{
  …
  // get Tinder's client ID
  String clientId = getTinderClientId();
  …
  this.webview.setWebViewClient(new WebViewClient() {
    public boolean shouldOverrideUrlLoading(WebView arg1, String url) {
      …
      // check if url is Instagram's OAuth API and extract the acess token for Tinder
      if (url.startsWith("api.instagram.com/oauth") && contains("code=") {
        String accessToken = url.substring(url.indexOf("code=") + 5, url.length());
        // then use this token to access user's profile info
        …
```

Case Study 2. Stealing user credentials

adkingkong steals user's Google account credentials

- an advertising app with 500,000 – 1,000,000 installations

```
package co.kr.adkingkong.libs.autoinstall;
…
public class GoogleWebLogin extends RelativeLayout {
  …
  // load Google login Web page
  this.webview.loadUrl("accounts.google.com");
…
 this.webview.setWebViewClient(new WebViewClient() {
   public void onPageFinished(WebView arg1, String url) {
     …
     //  inject JS to steal users' email and password
     arg1.loadUrl("javascript:
        if (document.getElementById('gaia_loginform') !== null) {
          document.getElementById('gaia_loginform').onsubmit = function onSubmit(form) {
            //  extract email and password from the login form
            email = document.getElementById('email-display').innerHTML;
            passwd = document.getElementById('Passwd').value);
        …");
     …
```

Case Study 3. Stealing and abusing Cookies

App **chatous** steals Facebook cookies and abuses them to collect sensitive user info and send spams

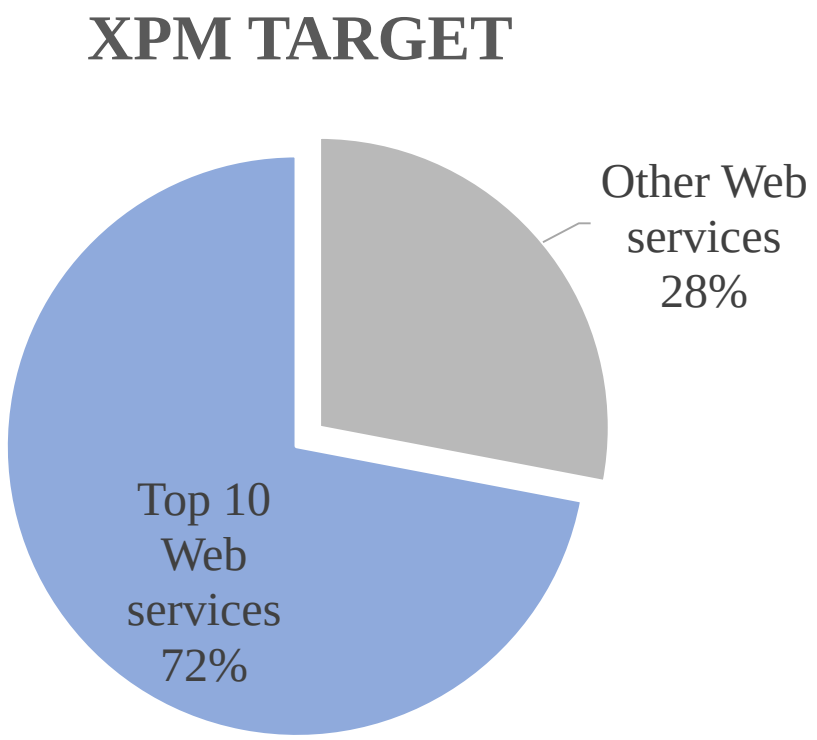
- a random chatting app with 10,000,000 to 50,000,000 installations

```
package com.chatous.chatous.managers;
…
public class FacebookManager extends Manager {
        …
        if (CookieManager.getInstance().getCookie(   “https://facebook.com") != null) {
          // get Facebook cookies
          cookies = CookieManager.getInstance().getCookie(   “https://facebook.com");
           // use these cookies to access user’s Facebook homepage
           DefaultHttpClient httpclient = new DefaultHttpClient();
           htttpclient.setCookieStore(cookieStore);
          HttpResponse response =
                    httpclient.execute(new   HttpGet(   “https://facebook.com/first_degree.php?   “ +…));
           …
          // get user’s friend list and send spam invitations
          List<String> friends = parse_response(response);
          for (friend: friends) {
              send_invitations(friend);
          }
```

Finding: XPM Targets and Their Awareness

- **More than 70% of XPMs target top popular Web services**
  - such as Google, Facebook, YouTube, Twitter, etc.

- However, most of them are **unaware** of such risks
  - all the above providers except Goolge allow sensitive Web services to be loaded into WebViews of any apps.
  - Google **are unable to** effectively prevent users from using WebView to do OAuth.
  - Google announcement, Aug 2016



Conclusion

- Measurement tool: automatically find **C**ross **P**rincipal **M**anipulation (XPM)
- First large scale empirical study on XPM in real-world
  - better understanding of the threat and development of countermeasures
  - confirm malicious App-to-Web attacks on both Android and iOS that already affect a large number of devices
- Dataset released: *https://xhzhang.github.io/XPMChecker/*

Q&A

Thanks !

Xiaohan Zhang
xh_zhang@fudan.edu.cn

Backup slides

Future work

1. What are other channels besides WebViews?
   - Hybrid frameworks, such as Cordova
   - Customized browser, such as Tencent X5
   - Other methods besides manipulation APIs

2. Can we directly detect malicious XPM behaviors?
   - Currently we rely on manual effort to confirm malicious XPM behaviors
   - Heuristic rules based on current findings

3. Defensive works

API Models

- Three types of APIs based on the source of manipulated Web URL
  - Type I: URL from a parameter
  - Type II: URL from base WebView instance
  - Type III: URL from a callback parameter (runtime URL)

```
1  CookieManager cm = new CookieManager();
2  cm.getCookie("www.google.com");
```

Listing 1: Type I, URL from a parameter.

```
1  WebView wv = new WebView(this);
2  // some code
3  wv.loadUrl("www.google.com");
4  // some other code
5  wv.evaluateJavascript("JS_CODE", ..);
```

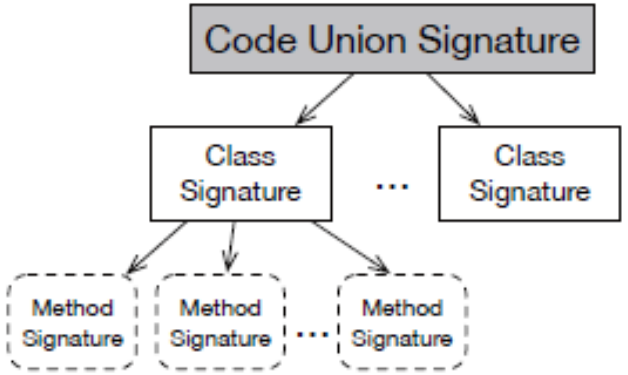
Listing 2: Type II, URL from base WebView instance.

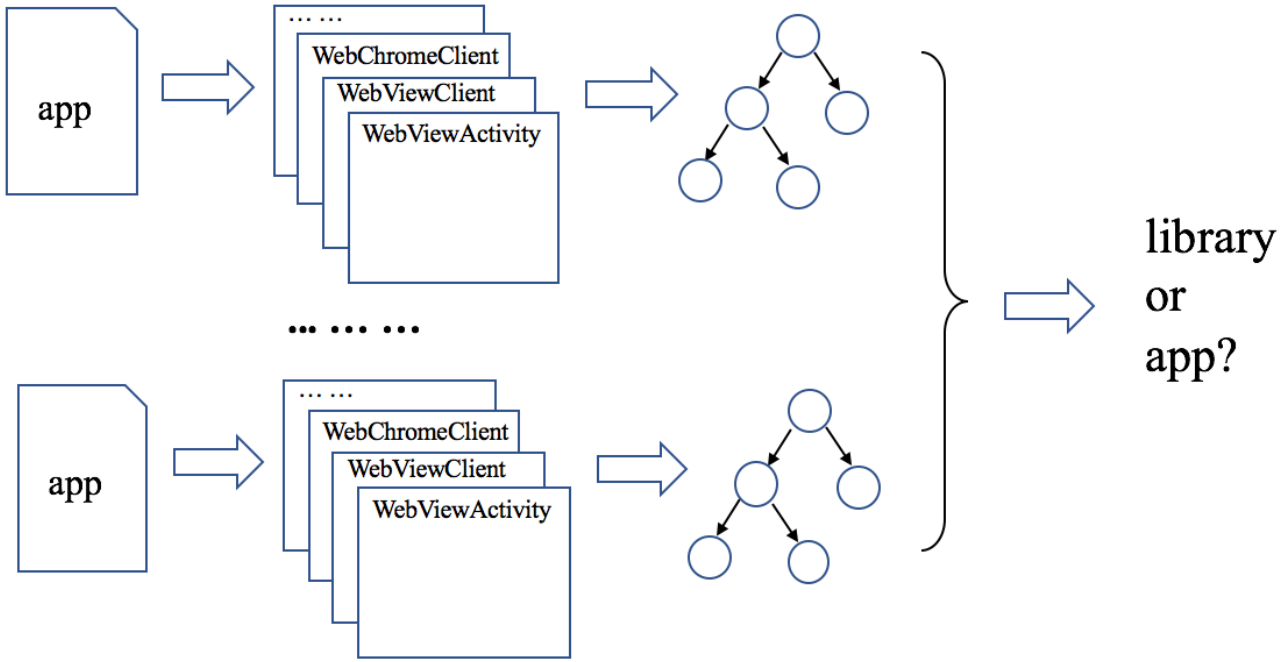
```
1  boolean shouldOverrideUrlLoading(WebView
       webview, String url){
2      if(url.startswith("www.google.com"))
           {
3          // some code
4      }
5      else if(url.equals("www.facebook.com
           ")){
6          // some other code
7      }
8      // other code
9  }
```

Listing 3: Type III, URL from a callback parameter.

Identifying third-party libraries

- idea: library code must exist in more than one apps with different developers
  - extra benefits: name recovery even some apps obfuscate their code
- Merkle-tree based code signature





[libPecker SANER'18]

Similarity Distance

$$sim\_distance(P_w, P_a) = \cos(P_w, P_a) = \frac{\sum_{i=1}^{n} A_i W_i}{\sqrt{\sum_{i=1}^{n} A_i^2}\ \sqrt{\sum_{i=1}^{n} W_i^2}}$$

where P_w and P_A is the Web principal and Code principal,
W and A is the searching vecotrs, with top n terms and their frequencies

Determine the threshold θ

- Manually labeled 1200 $<P_w, P_A>$ pairs
  - 1000 are used to determine threshold θ
  - 200 are used to test the performance
- ROC & EER point
  - θ = 0.3134, AUC = 97.8%
- **27**% improvement in precision comparing to simple word similarity

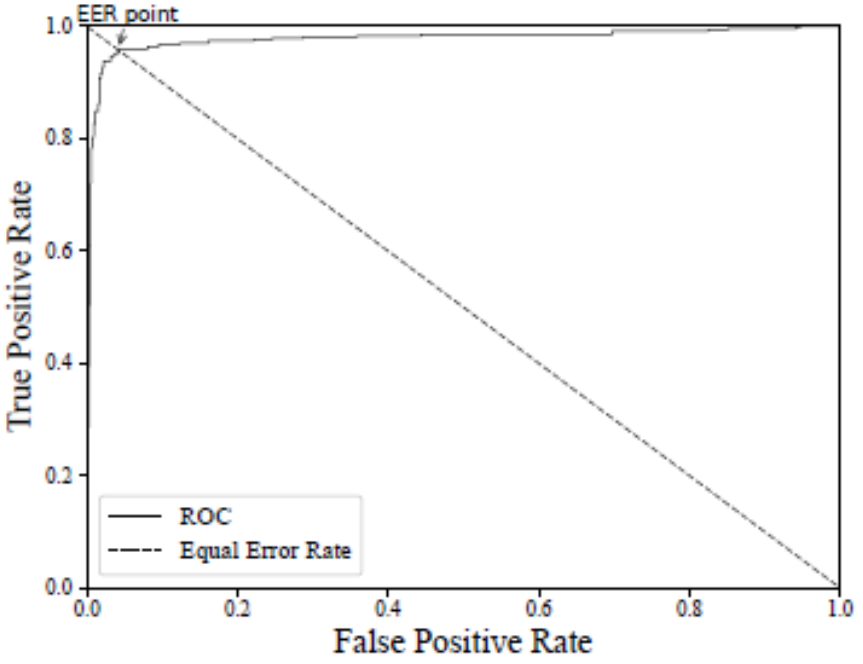


Figure 4: ROC curve for varied θ in XPMClassfier with 1000 manipulation points.

Case 3 More details

- User complaints on malicious Chatous app