Measuring the Insecurity of Mobile Deep Links of Android

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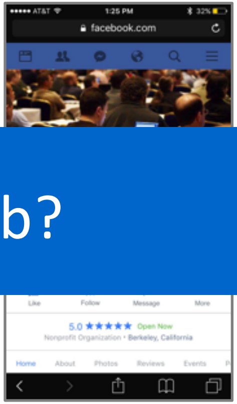
VirginiaTech
Invent the Future

Web Browsing is Going Mobile

- Users spend more time on mobile devices[1]
  - Mobile devices ~ 3.1 hours
  - Laptops/Desktops ~ 2.2 hours

- Native apps: the new web interface
  - Shorter loading time



Apps are the future of the web?

[1] Mary Meeker, Internet Trends 2017 - Code Conference, KPCB, 2017

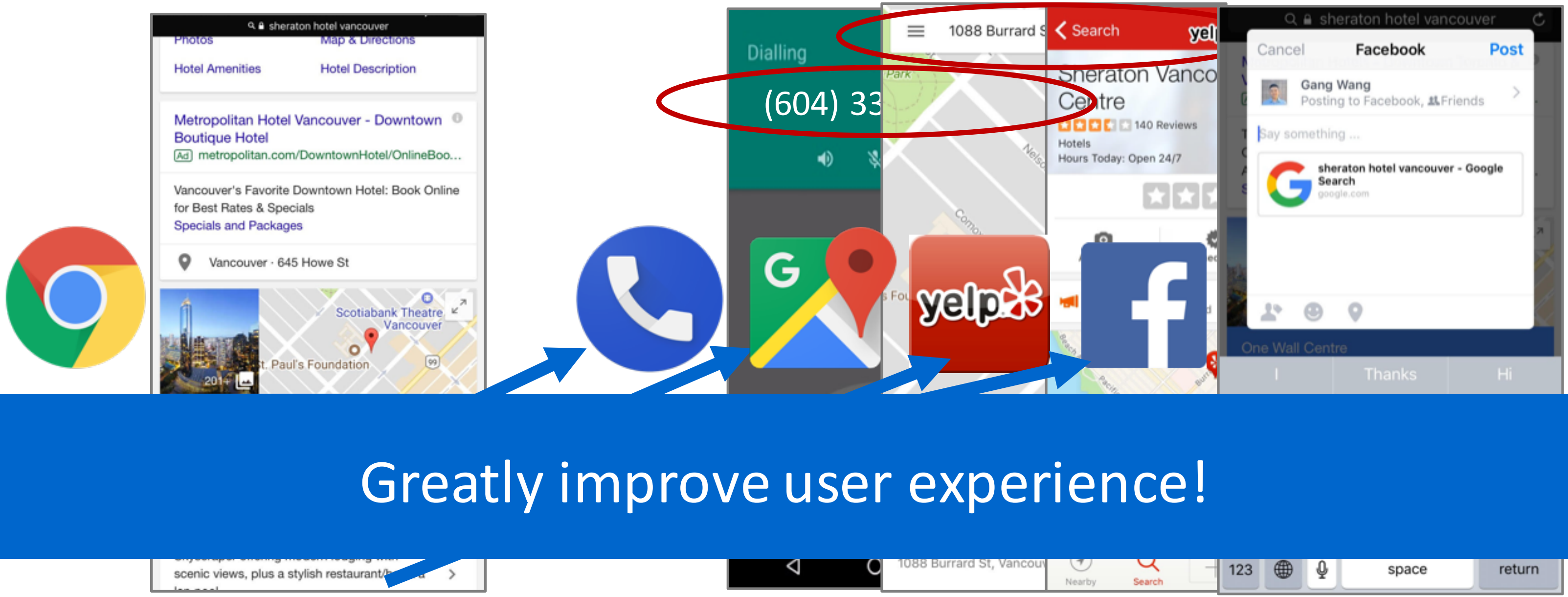
Apps vs. Mobile Websites

- Apps cannot replace websites yet
  - Apps sit in a "walled garden"
  - Difficult to navigate across apps
  - Difficult to search and access in-app content globally

- Apps + mobile websites eco-system
  - Complementary to each other
  - Likely to co-exist (for a long time)

Web-App Communication via Deep Links

- Deeper integration of websites and apps
  - Mobile deep links: URIs pointing to pages inside apps



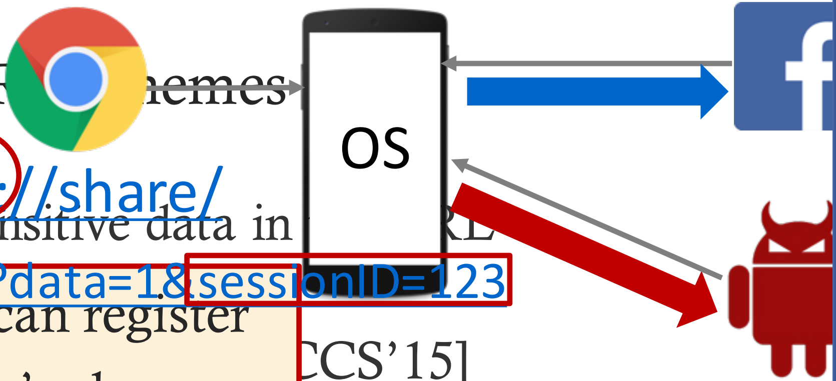
Greatly improve user experience!

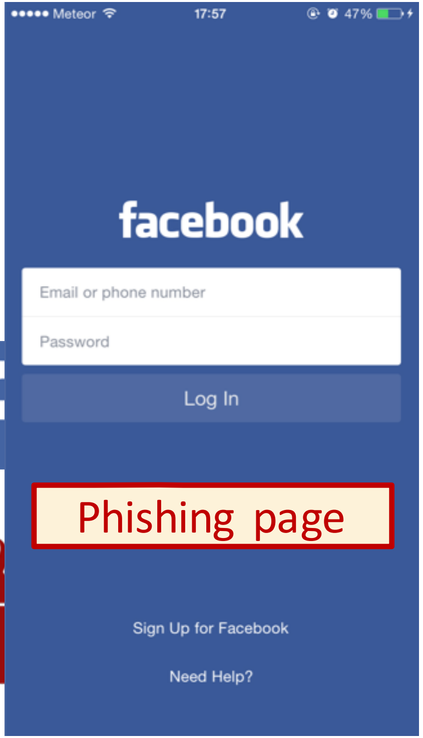
Hijacking Risks of Deep Links

- Scheme URL: mobile deep link v1.0
  - Designed for functionality, no security features
  - Apps can register their own scheme to the OS
  - Android and iOS since 2009

- Hijacking UR hemes
  - Phishing
  - Stealing sensitive data in RL
  - CCS'15]

Any app can register other apps' schemes





facebook

Email or phone number

Password

Log In

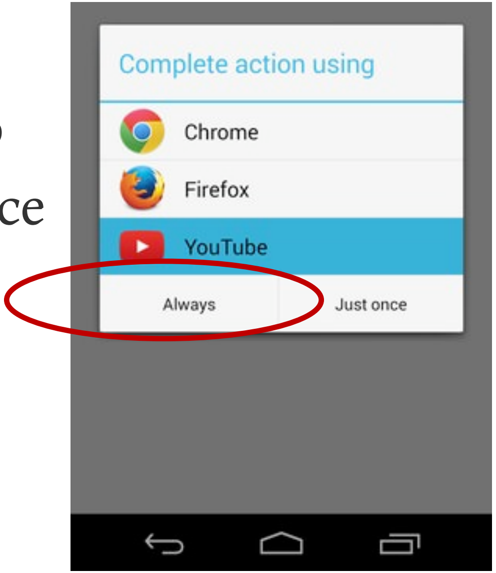
Phishing page

Sign Up for Facebook

Need Help?

Defense Relying on Users

- Prompt users when multiple apps have the same scheme
- But, user prompting can be skipped
  - If the malicious app installed before the real app
  - If the malicious app tricked users to set preference
- User as the only defense = bad defense



Deep Link v2.0 Prevents Link Hijacking

- App links
  - HTTP/HTTPS links only, no custom schemes
  - Requires app link association

~~fb://~~ ➔ https://facebook.com/

- Intent URL
  - Explicitly specify the target app by package name

~~fb://~~ ➔
intent://p#Intent;scheme=fb;package=com.facebook;end

Uniqueness guaranteed by the app market

This Study

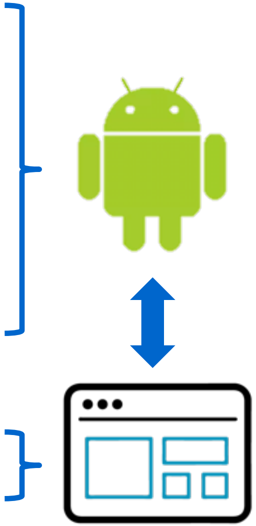
- Research questions
  - How are different mobile deep links used in practice?
  - How likely is an app's scheme hijacked by another app?
  - How effective are the new deep link mechanisms in mitigating the hijacking threats?

- Large-scale empirical measurements
  - Deep links across web and apps
  - Primarily focus on Android (>80% market share)

Let the DATA speak

Outline

- ~~Introduction~~
- The Adoption of Mobile Deep Links
  - Scheme URL vs. App Link
  - App Links: Vulnerabilities & Misconfigurations
- Characterizing Hijacking Attacks
- Hijacking Threats on the Web



Datasets

- Android apps (25 app categories)
  - 164,322 most popular apps, December 2014
  - 164,963 most popular apps, August 2016
  - 115,399 apps in both snapshots

Register the same link?

- Popular websites
  - Alexa top 1 million domain's index page, October 2016
  - Dynamic crawler to mimic Chrome mobile browser (OpenWPM[1])
  - Lower bound of mobile deep links on the web

Hijacked links on the web pages?

[1] ENGLEHARDT, S., AND NARAYANAN, A. Online tracking: A 1-million-site measurement and analysis. In *Proc. of CCS* (2016)

Deep Link Usage in Apps

Dataset	Total Apps	Apps register Scheme URLs	Apps register App Links	Apps register either Links
2014	164,322	10,565 (6.4%)	4,545 (2.8%)	12,428 (7.6%)

~90% growth rate in deep link adoption

Are App links properly verified?

Key observations

- Mobile deep links are getting popular among apps
- The vulnerable scheme URLs are still increasinly used

App Link Verification

- App link association to prevent link hijacking

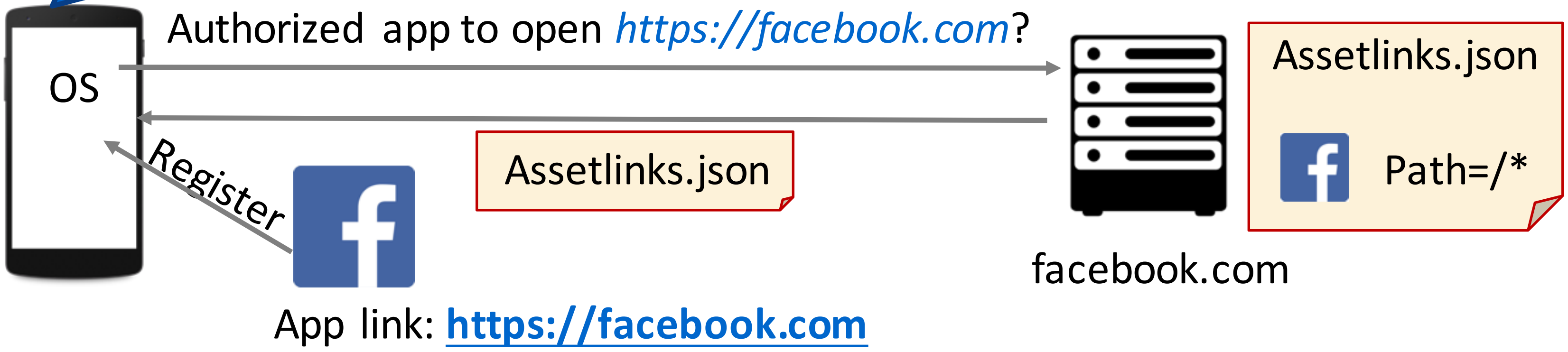
ved

e App link and the web domain

“universal link”

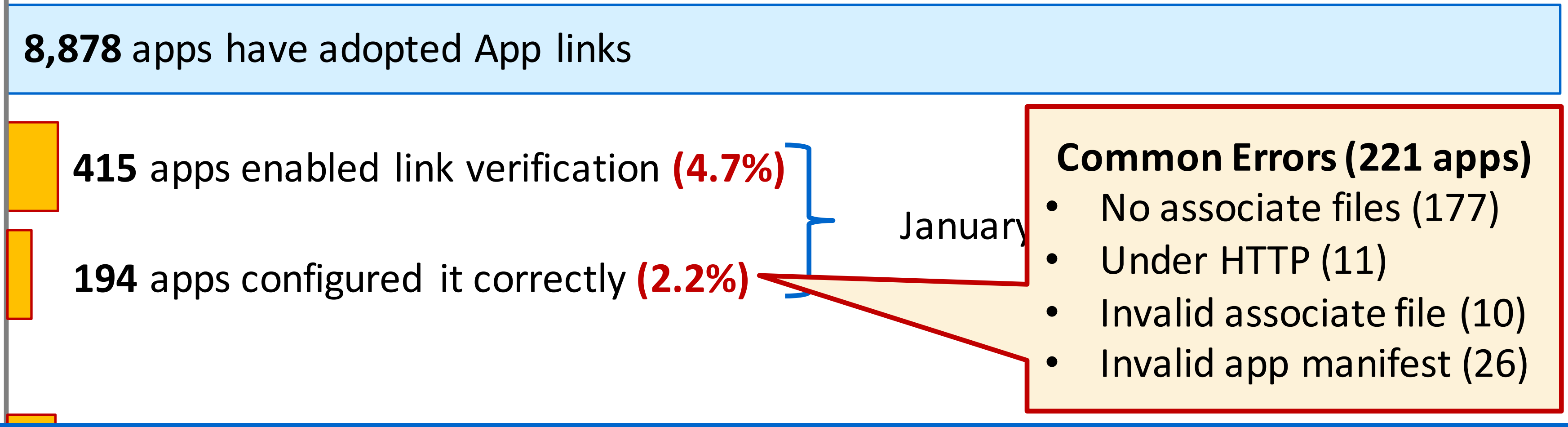
Unverified links

- Android: still works, but trigger user prompt
- iOS: cannot open the link in the app



OS
Authorized app to open *https://facebook.com*?
Register
Assetlinks.json
Assetlinks.json
Path=/*
facebook.com
App link: **https://facebook.com**

App Link Verification in Practice



8,878 apps have adopted App links

415 apps enabled link verification **(4.7%)**

194 apps configured it correctly **(2.2%)**

January

Common Errors (221 apps)

- No associate files (177)
- Under HTTP (11)
- Invalid associate file (10)
- Invalid app manifest (26)

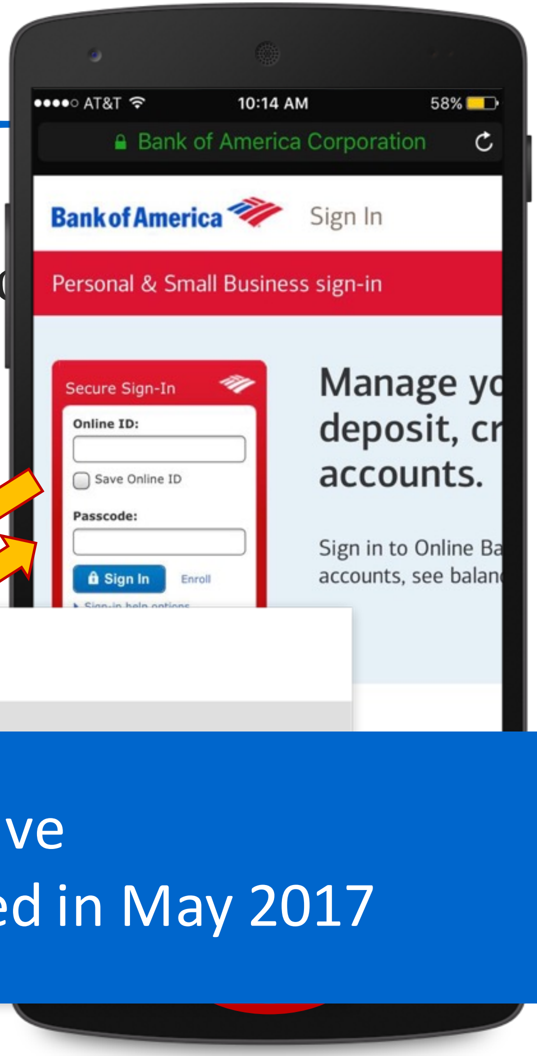
- Rarely do apps verify their App links correctly
  - A lack of incentives: unverified App links can still open apps
- Configuration errors are not identified and mitigated quickly

App Link Vulnerability: Over-

- Allows unverified app links to skip user pr

  links that

- Hijack password without user knowledge!
- HTTPS does not help



https://recipe.com/cupcake

Manifest.xml
Intent filters
Open with

- Root cause: the preference setting is too excessive
- Reported to Google in Feb 2017, case established in May 2017

Outline

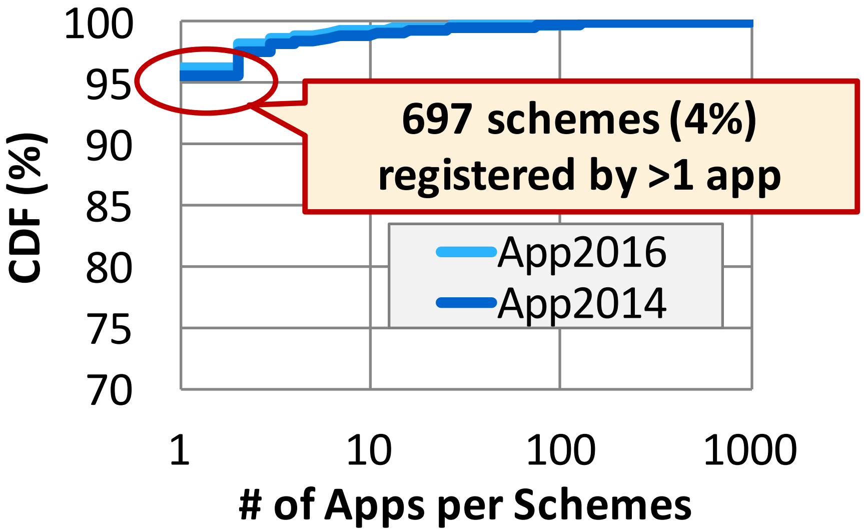
- ~~Introduction~~
- ~~The Adoption of Mobile Deep Links~~
-

- Scheme URLs are still widely used
- App links are rarely verified correctly
- App links introduce a new vulnerability

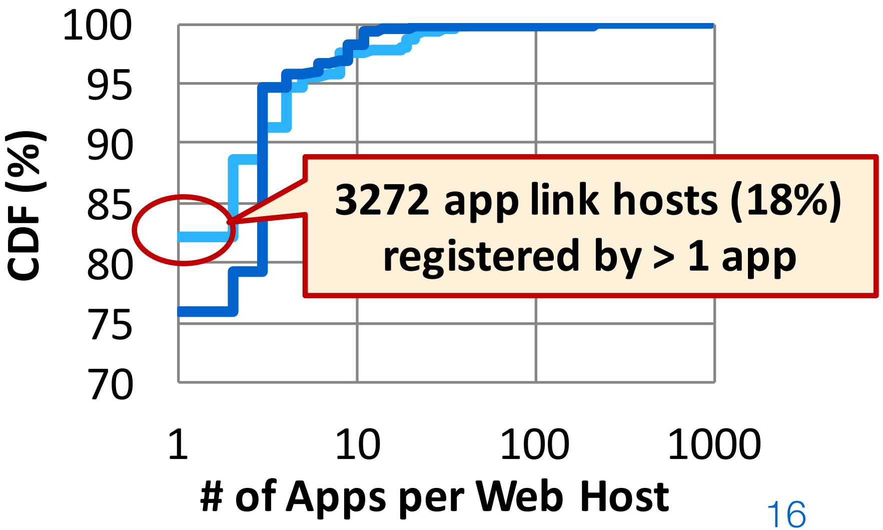
- Hijacking Threats on the Web

Identifying Potential Hijacking Apps

- Link collision: multiple apps that registered the same Link
  - 18,839 unique schemes (e.g., fb://)
  - 18,561 unique App link hosts (e.g., facebook.com)



697 schemes (4%) registered by >1 app



3272 app link hosts (18%) registered by > 1 app

Classifying Link Collisions

Not all link collisions are malicious

Scheme URL

Functional scheme

Represents a common functionality
e.g. **geo://, tel://, file://**

Third-party scheme

Used by 3rd-party library and APIs
e.g., **x-oauthflow-twitter://**

Per-app scheme

Represents individual apps
e.g., **fb://, twitter://**

App Link

~~**Functional web host**~~

N/A

Third-party web host

e.g., **zxing.appspot.com**

Per-app web host

e.g., **facebook.com, twitter.com**

Potentially Malicious Hijacking

Classifying Per-App Hijacking

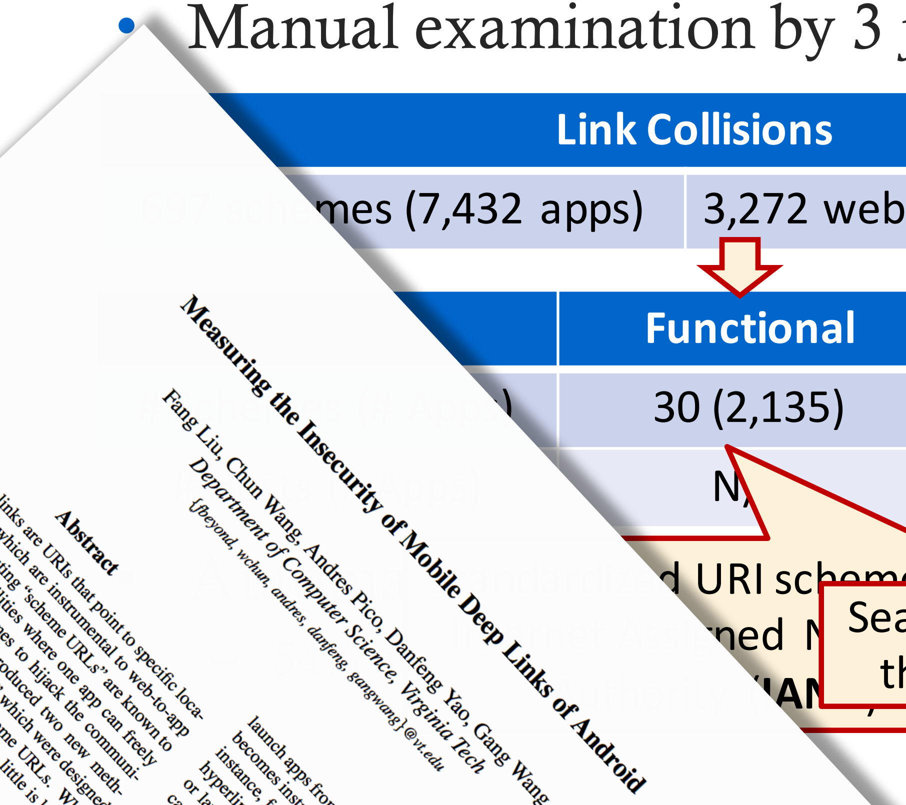
- Manual examination by 3 judges

Link Collisions	
697 schemes (7,432 apps)	3,272 web hosts (2,868 apps)

	Functional	3rd-party	Per-app
# Schemes (# Apps)	30 (2,135)	197 (3,972)	149 (893)
[illegible] (# Apps)	N/	137 (999)	2,314 (1,593)

Search for online the 3rd-party libs and APIs

Not from the same developer



Measuring the Insecurity of Mobile Deep Links of Android

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Abstract

links are URIs that point to specific loca- which are instrumental to web-to-app ting "scheme URLs" are known to lities where one app can freely es to hijack the communi- oduced two new meth- which were designed me URLs. W little is

launch apps fro becomes inst instance, f hyperli or la

18

Hijacking Case Studies

Google Google Maps

- Traffic hijacking
  - **google.com** registered by 480 apps (305 non-Google developers)
  - **google.navigation://** registered by 79 apps (32 developers)
  - Other popular targets facebook airbnb YouTube tumblr.

- Competing Apps
  - Careem (5M downloads)

    widely integrated with hotel websites/apps
  - QatarTaxi (10K downloads)

    also registered **careem://***

Case Studies (Cont.)

- Redirection apps and MITM
  - Resolve deep links and redirect users to target apps
  - Hard-coded mapping, without permission of the target app
  - Log URL and parameters to files

- Example: URLLander
  - Registered payments.ebay.com while the official eBay app did not
  - Registered www.paypal.com (SESSIONID parameter)

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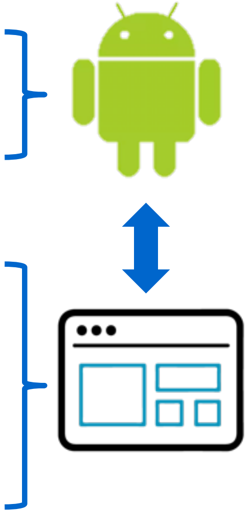
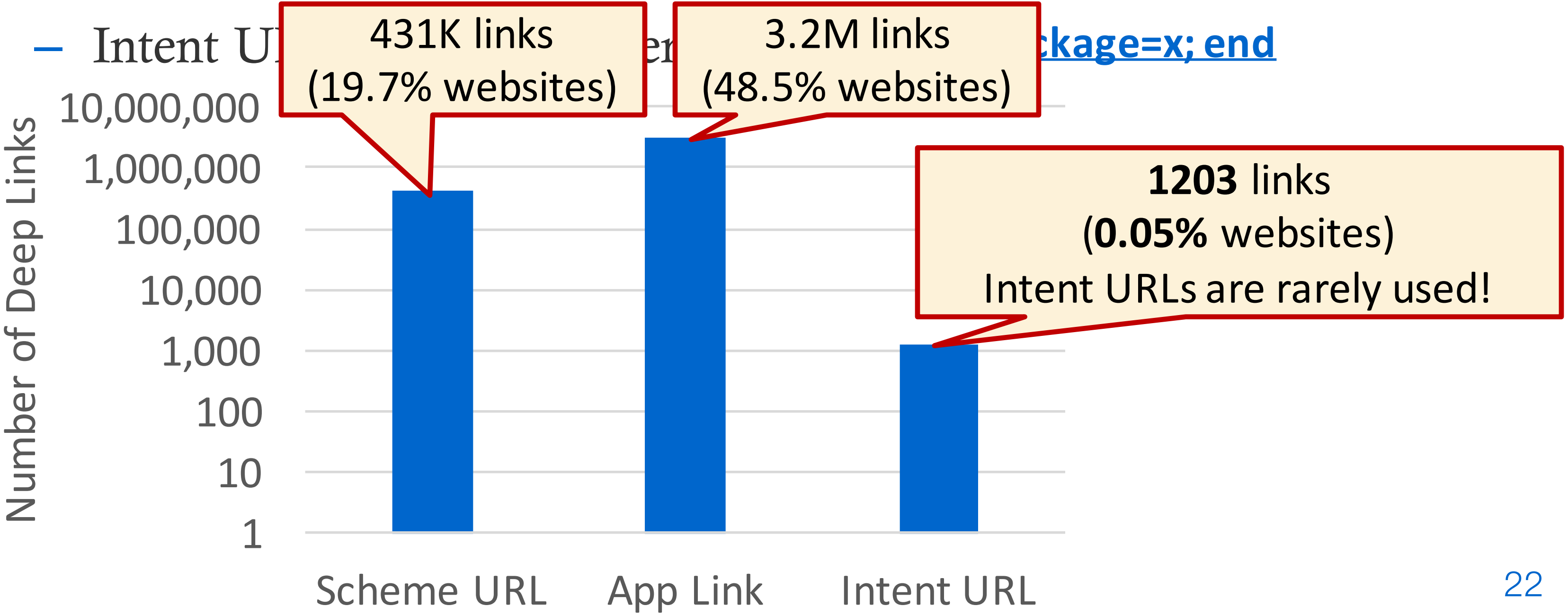
- ~~Characterizing Hijacking Attacks~~
- Hijacking Threats on the Web
  - Usage of Intent URL
  - Hijacked App Links vs. Scheme URLs



Deep Links on Alexa Top 1M Websites

- Extracting deep links from web pages
  - Regular expression matching with scheme URLs/App links
  - Intent U er **ckage=x; end**



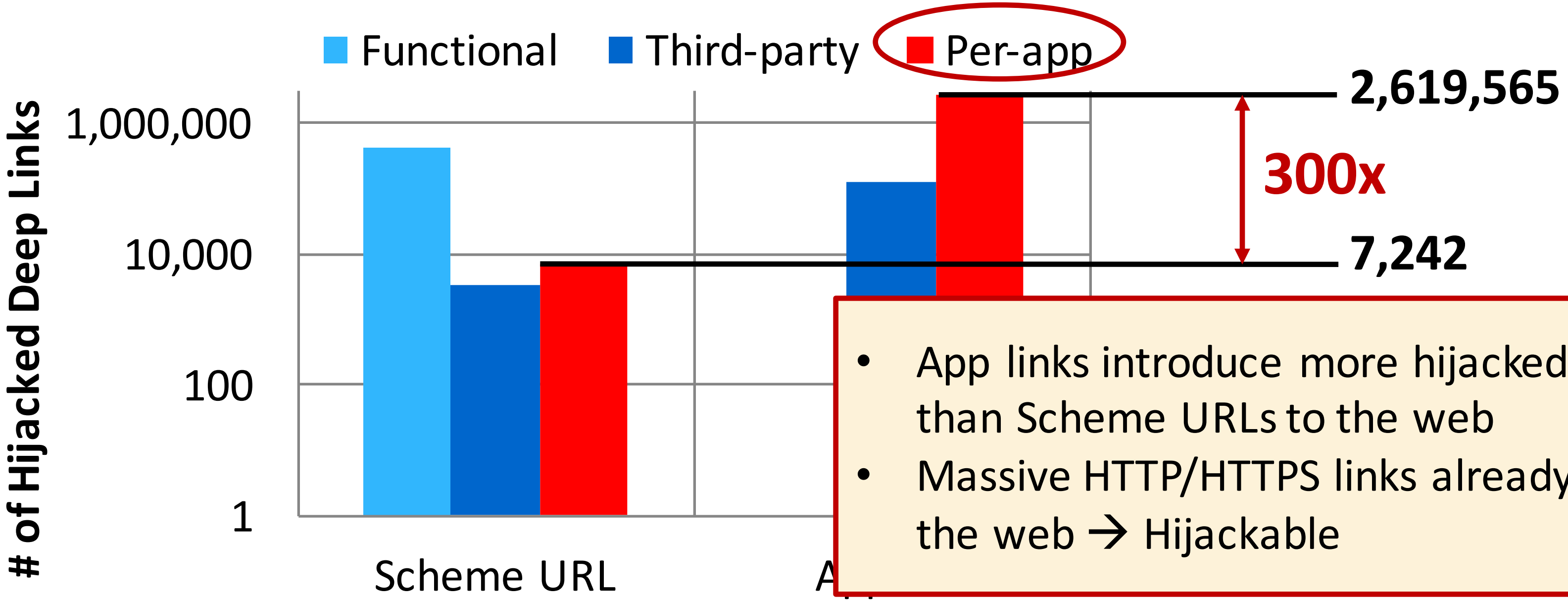
431K links (19.7% websites)

3.2M links (48.5% websites)

1203 links (**0.05%** websites) Intent URLs are rarely used!

“Hijacked” Deep Links on the Web

- Deep links on the web that may take users to the wrong app
  - Deep links registered by multiple apps vs. links on the web pages



- App links introduce more hijacked links than Scheme URLs to the web
- Massive HTTP/HTTPS links already exist on the web → Hijackable

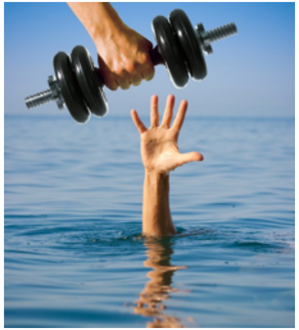
Discussion

- Scheme URLs are still widely used by apps and websites

- The new App link not only fails to improve security, but significantly increases hijacking risks
  - App links are rarely verified (2.2% apps did it correctly)

iOS App links: 1,925 out of 12,570 (**15%**) apps have misconfigured the verification

heme URLs



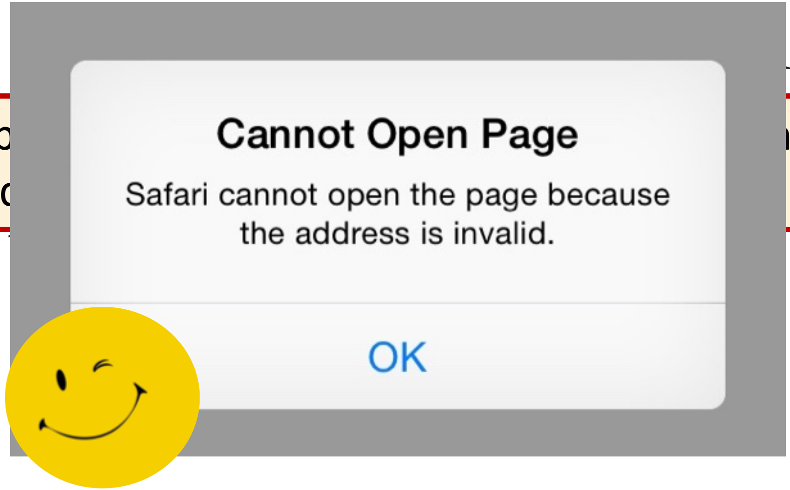
- Intent URLs are rarely used on the web

Countermeasures

- Disable per-app scheme
  - Whitelist functional schemes
- Enforce App link verification
- Fix App link over-permission
  - Set it to the link/domain level

- Break legacy links on the web
- s

[1]Ab ng
And


Cannot Open Page

Safari cannot open the page because the address is invalid.

[1] https://developer.android.com/about/dashboards/index.html

Thank You