WindowGuard:
Systematic Protection of GUI System in Android

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Android Graphic User Interface

- Android GUI greatly promotes user experience
- One of the most sophisticated sub-systems in Android

Android GUI Security

- However, Android GUI system has been plagued by a variety of attacks that compromise the integrity and availability of Android GUI system.
- We call them **GUI attacks**

GUI Integrity Breach

- Mobile phishing attack[1,2]

[1] Chen et al. USENIX'14

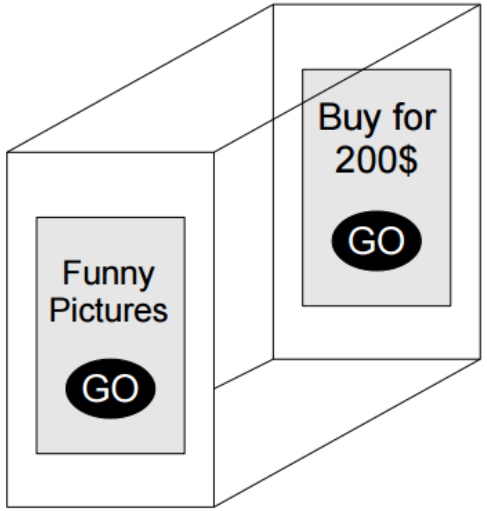
[2]Android Trojan Svpeng

GUI Integrity Breach

- Mobile phishing attack (USENIX'14, Svpeng malware)
- Task hijacking attack (USENIX'15)

GUI Integrity Breach

- Mobile phishing attack (USENIX'14, Svpeng malware)
- Task hijacking attack (USENIX'15)
- Tapjacking attack tricks user perform undesirable actions [4]



[4]Blackhat 12

GUI Availability Breach

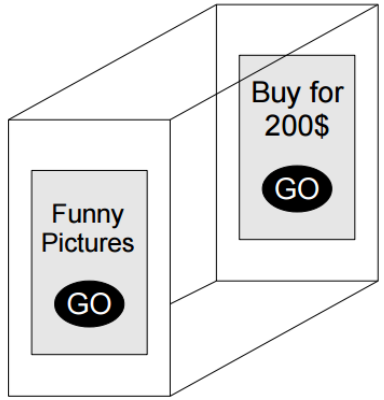
- Ransomware migrates to mobile environment[1], infecting 900K user devices within 2 years
- Adware repeatedly presents unwanted (sometime "uncloseble") ad windows [2]

[1]Ransomware Police Locker

[2]Rastogi, NDSS'16

Serious Security Threats

Σεριουσ τηρεατσ



Existing Defense

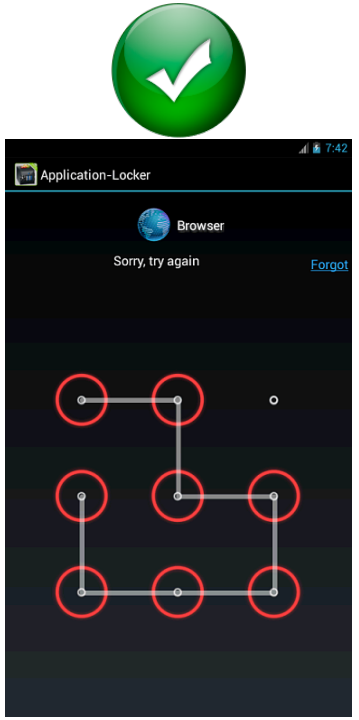
- Google has taken steps to remedy the security problems in newer Android versions
  - Add security attributes to GUI components, e.g. `setFilterTouchesWhenObscured`
  - Require explicit user consent when using certain permissions

- Challenges: adoption of the security features takes time
  - Compatibility issues for existing functionalities
  - Older devices or apps are vulnerable

Existing Defense

- Bianchi et al. (Oakland'15) proposes a two layer defense
  - An app vetting process based on static analysis
  - On-device defense mechanism

Ransomware: FBILock-A



App Locker

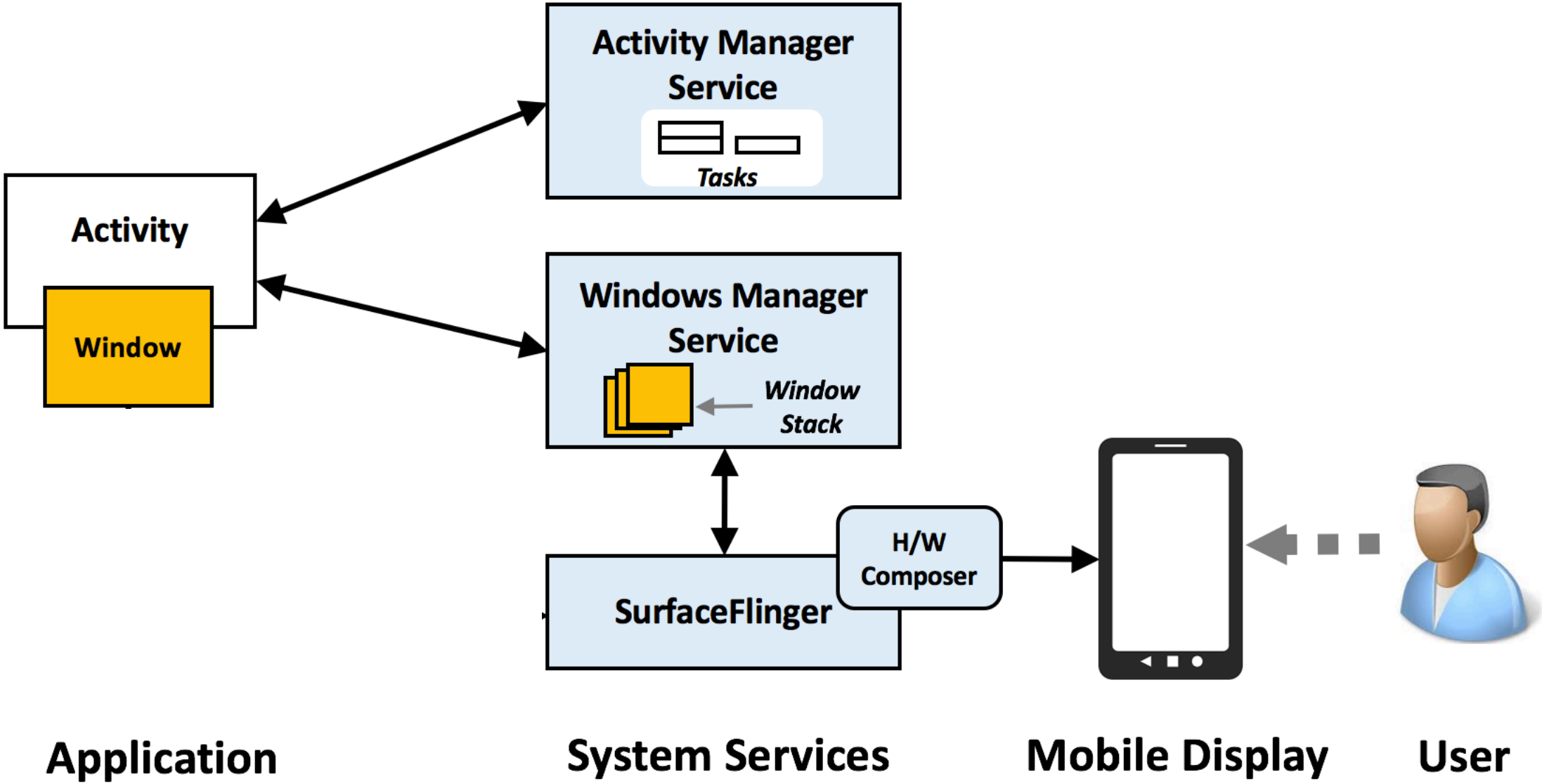
Contributions

- We systematically scrutinize the security implication of Android GUI system and find the root cause of GUI attacks
- We propose a new UI integrity model for Android - **Android Window Integrity (AWI)**
- We create WindowGuard – an implementation of AWI that protects user devices from all known GUI attacks

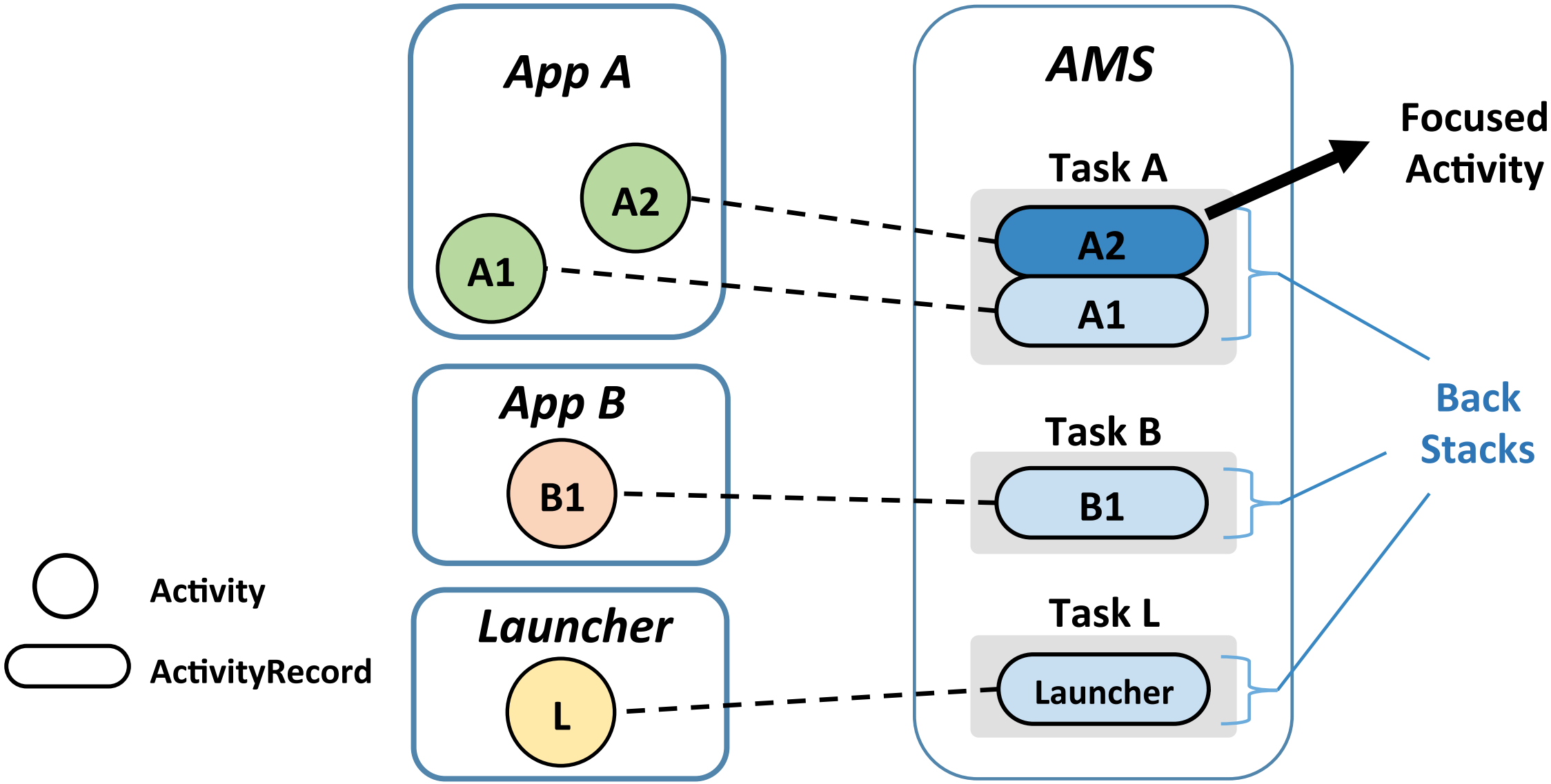
Building Blocks of GUI System

- Activity:
  - An app component that provides GUI to the user
- Window:
  - Conceptually, a visual area on screen that shows the GUI
  - A container to hold all GUI components
- An activity must include a window

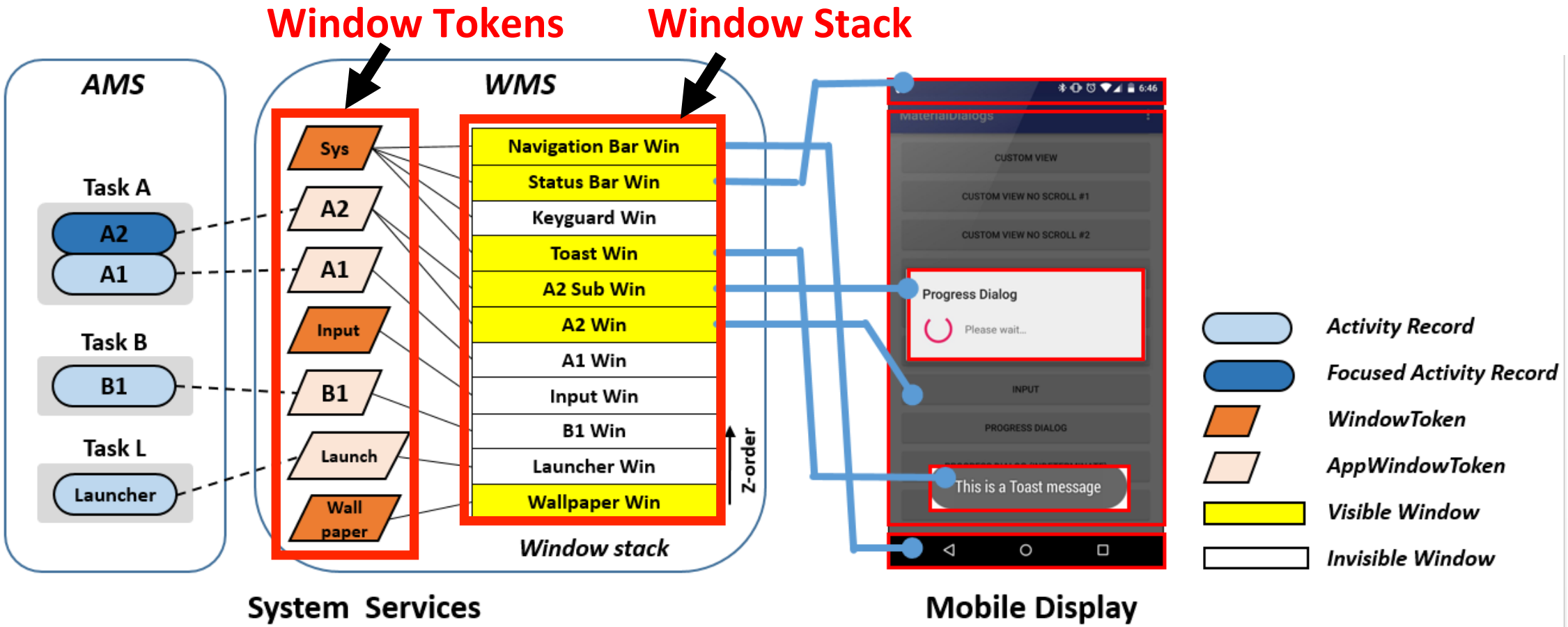
Android GUI System



Activity Management



Window Management



Important Notions:

Window stack, Window Z-order, Window visibility, **Window Token**

Android GUI System Security

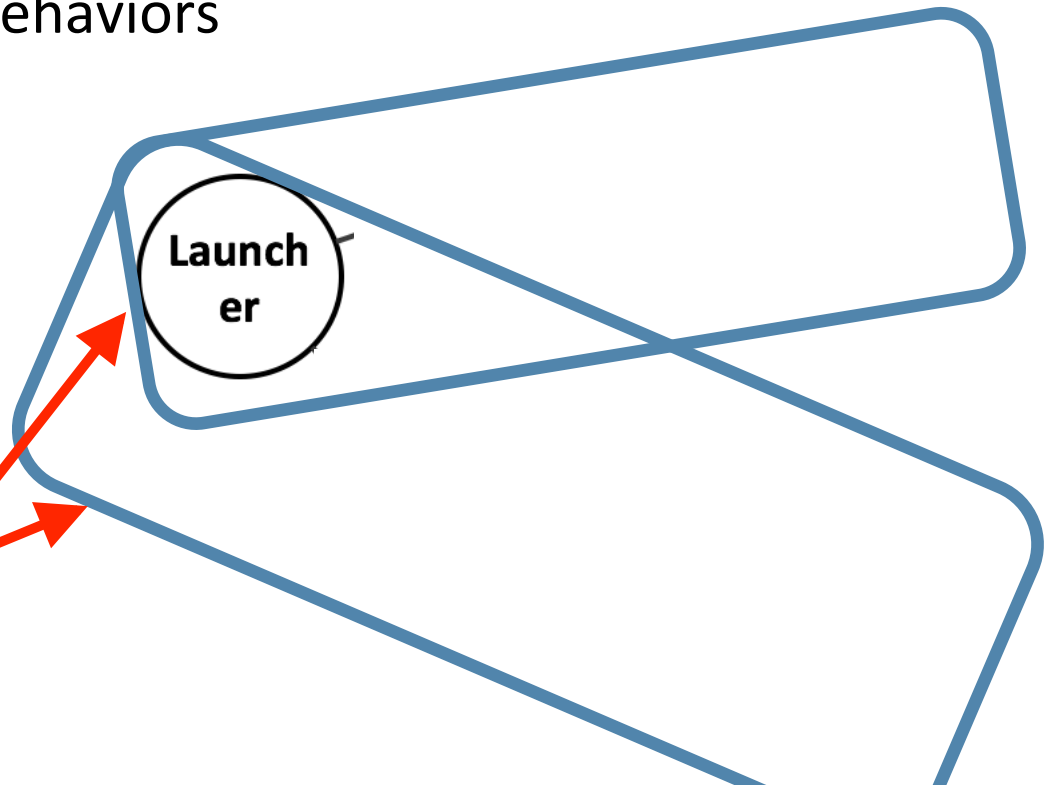
Existing security mechanisms:

- App sandboxing, protected by Linux UID
- Window token
- Permission

Security Risk: an **user session** is beyond the scope of existing security mechanism protections

Activity Session

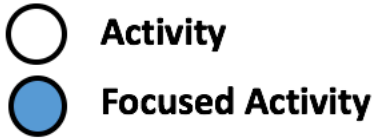
- An **user session** **or** **activity session** is a sequence of activities that user has interacted in a particular job
  - Activities in an user session may come from different apps
  - Great flexibility that allows apps to control activity and window behaviors



No security guarantees

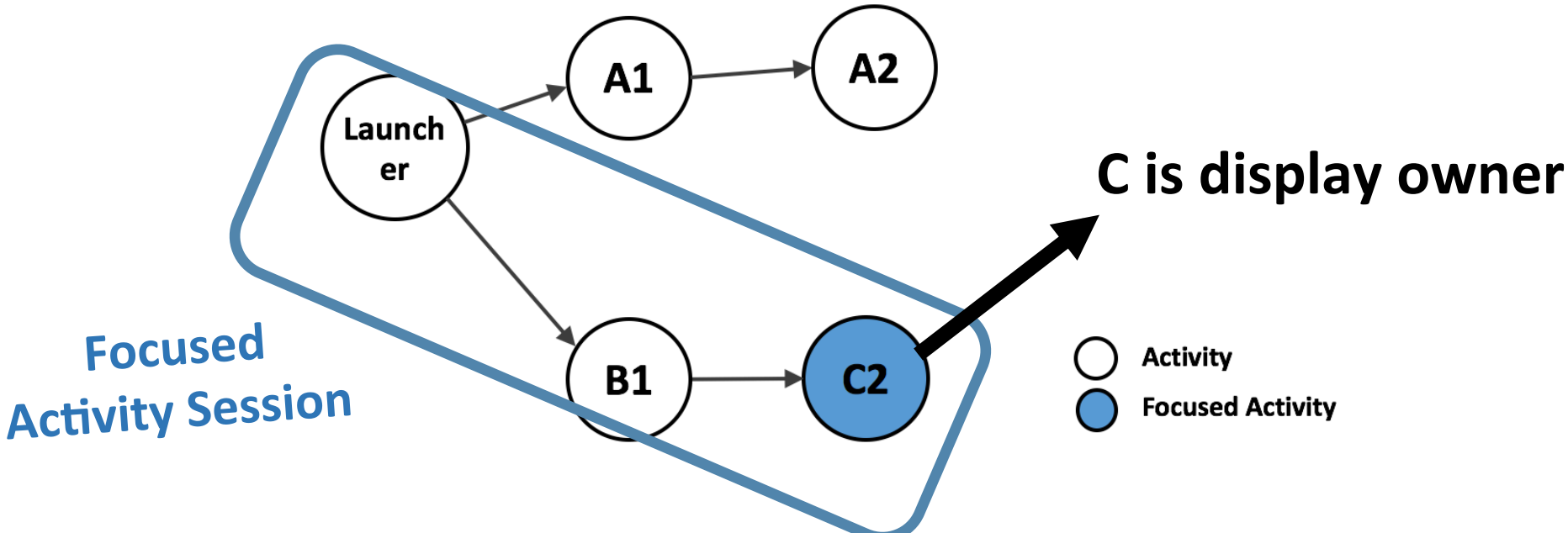
Two activity sessions:

- **Launcher -> A1 -> A2**
- **Launcher -> B1 -> C2**



Android Window Integrity (AWI)

- **Key principle**: no app has permission to perform any operations that would adversely affect other app's activity session
  - ***Display owner***: display owner is the app of focused activity. Display owner "owns" the screen. Display owner and the focused user session is protected by AWI.



Android Window Integrity (AWI)

AWI is composed of three legitimacy:

- Legitimacy of activity session
- Legitimacy of future windows
- Legitimacy of existing windows

Legitimacy of Activity Session

Criteria: focused activity session should always be consistent with the back stacks in AMS

Formally:

$$\exists\{bs_1^*, bs_2^*, ..., bs_n^*\} \subseteq \beta : s_{fg} = (bs_1^* \parallel bs_2^* \parallel, ..., \parallel bs_n^*)$$

bs_i^* : a back stack (a sequence of activities)

β : all back stacks in the system

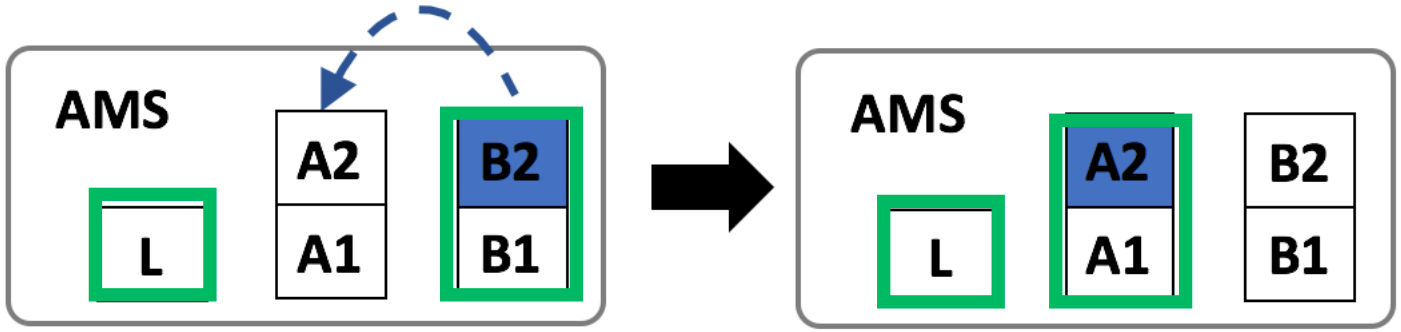
s_{fg} : focused activity session (a sequence of activities)

Valid System State

A valid example:

Focused Activity

Tasks:

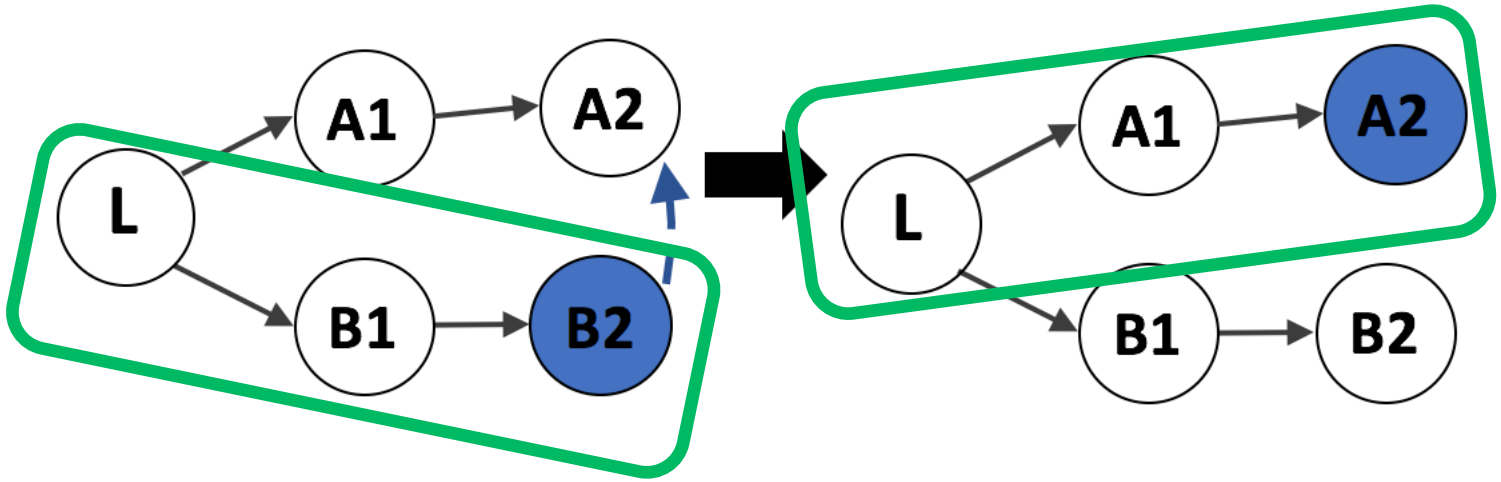


Activity sequence:

L -> B1 -> B2

L -> A1 -> A2

Activity Sessions:

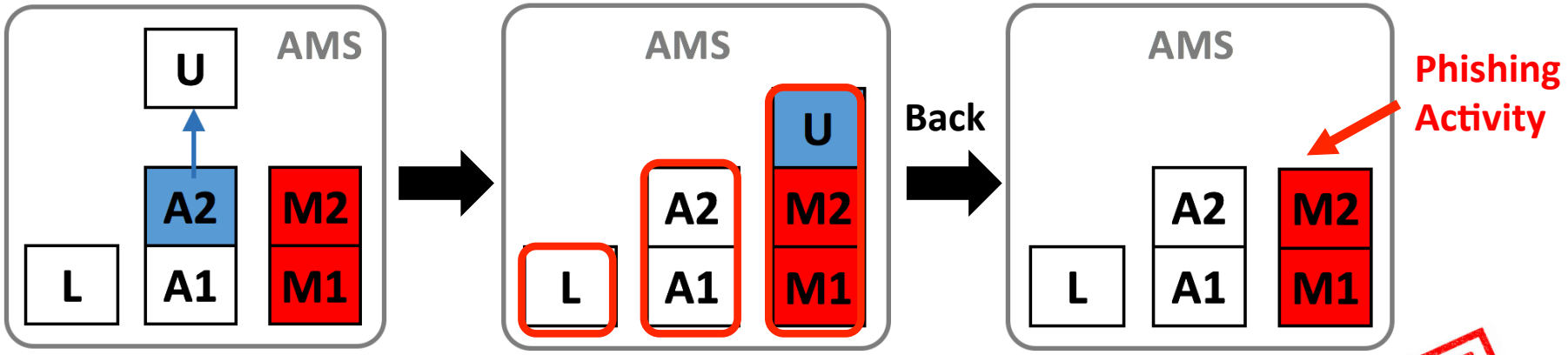


Invalid System State

A task hijacking example:

Focused Activity

Activity Stacks:

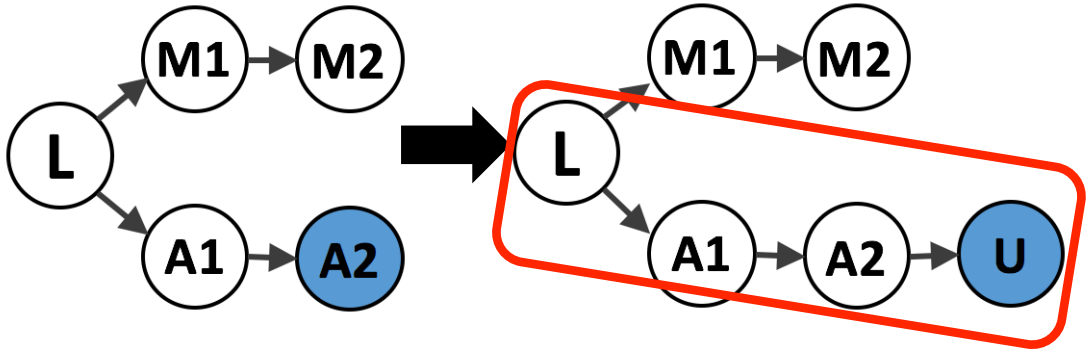


Activity Sequence:

L -> A1 -> A2

L -> A1 -> A2 -> M1 -> M2 -> U

Activity Sessions:

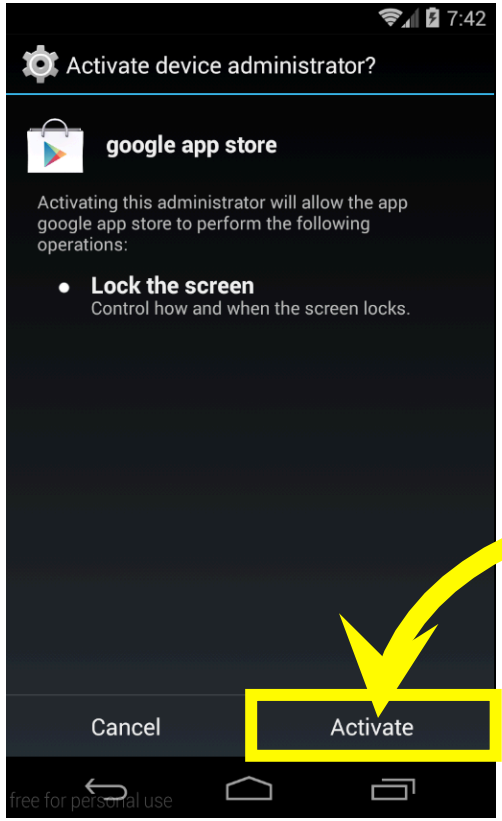


WindowGuard

- We implement AWI as a Xposed module – *WindowGuard,* by hooking various framework components in Android GUI system
  - WindowGuard prompts the user for the final decision once a security violation occurs. This design meets the diverse needs of users and app developers in the Android ecosystem.
  - 5 security features, such as integrity of activity session, legitimacy of windows start/resume, etc.

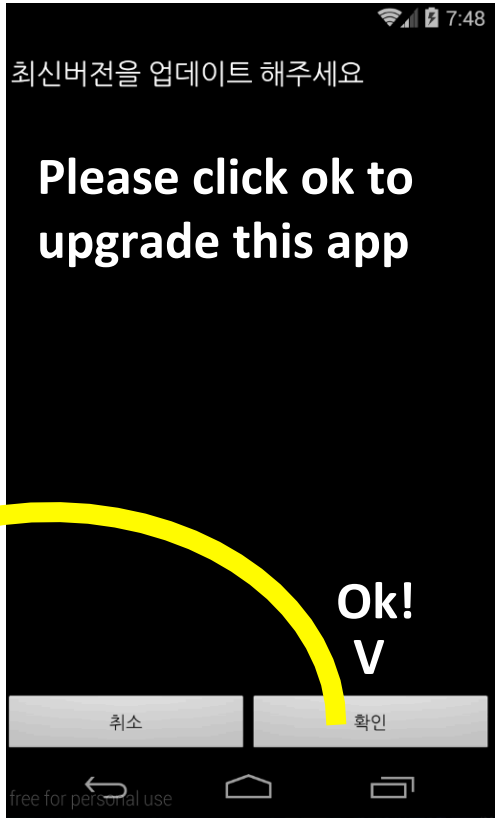
Tapjacking Attack Example

An Android malware (BankRob) example:



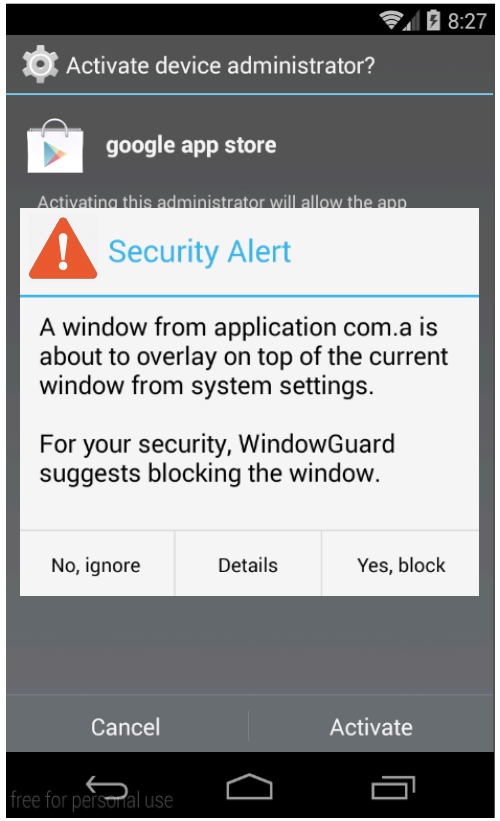
Device Admin Request Confirmation Dialog

(a)



Tapjacking Overlay Window

(b)



indowGuard Security Alert

(c)

Effectiveness

Attack Vectors	Consequences				
	Data Stolen	Privilege Escalation	User Spoofing	Denial of Service	Malware Infection
UI Interception	☠				
Tap-jacking		☠			
Back-button Hijacking	☠		☠		
Activity launch hijacking	☠		☠		
User Monitoring Attack	☠				
Adware				☠	☠

WindowGuard can defeat all known GUI attacks.

Usability

- We evaluate the usability by automatically exercising each of 12,060 most popular Google Play apps for 5 minutes on devices with WindowGuard enabled

Security Feature	Alert Msg	# of Apps	% of Apps
Activity Session Legitimacy	T, N	12	0.10
New Window Access Control	D	39	0.32
Existing Window Legitimacy	T, N	14	0.12
New Activity Control	D	69	0.57
Activity Resume Legitimacy	D	11	0.09
Any Feature(s)		124	1.03

- **Only 1% apps triggers security alert**
- **Among those apps that trigger security alert, 62.5% triggers security alert only once**

Limitation

- WindowGuard introduces 1% of false positives
- The flexibility of letting user make the final security decision may introduce false negatives.
- The current implementation of WindowGuard is based on Xposed, which can only be used on rooted devices.

PENNSTATE

Conclusion

- We systematically scrutinize the security implication of Android GUI system
- We propose a new UI integrity model − Android Window Integrity model
- We implement WindowGuard, which is able to effectively defeat all known GUI attacks

Thank you!

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Back-up Slides

Existing Defense

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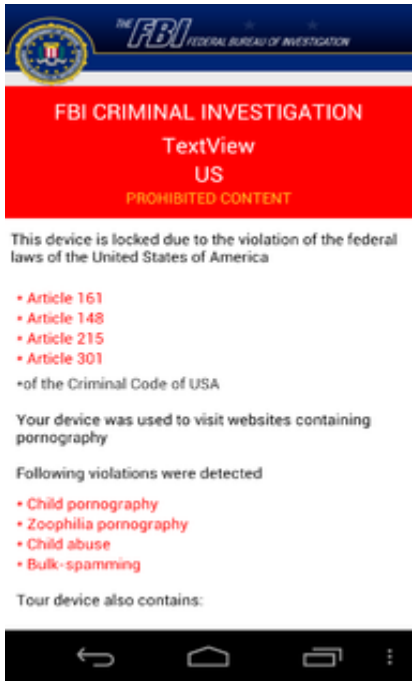
  - An app vetting process based on static analysis



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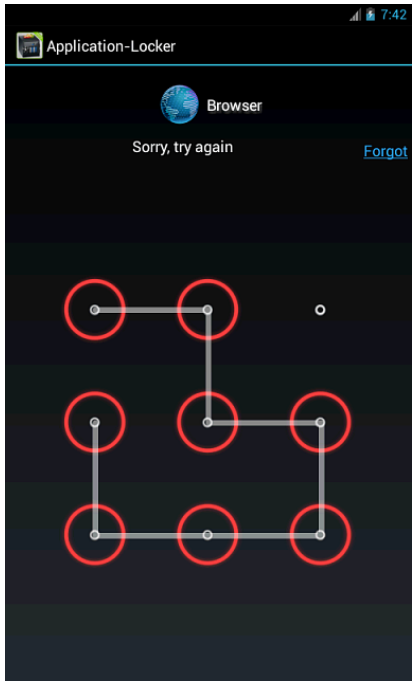
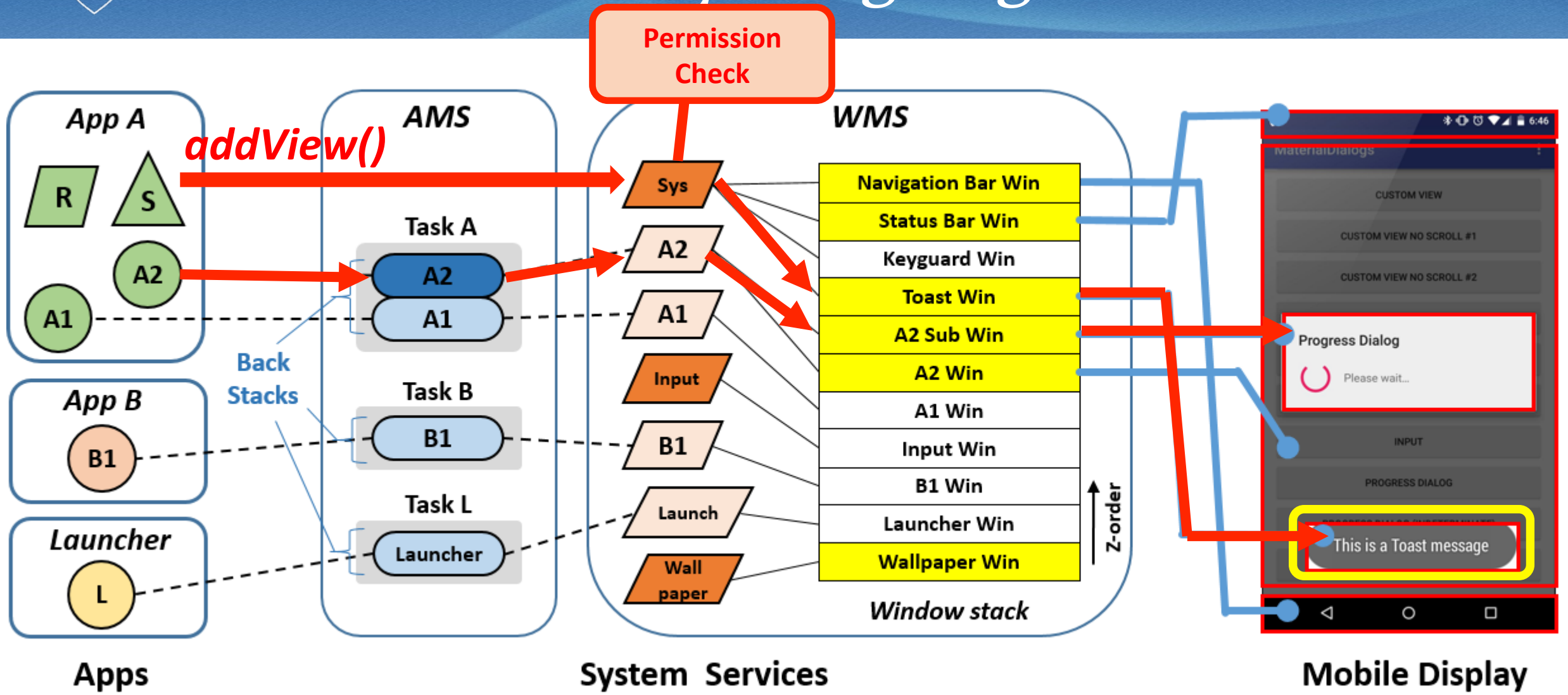


App Locker

Challenges

- Challenges of existing on-device defense
  - Negative impact on user experience
  - Low detection accuracy (max. 76% in an user study)
  - Only capable of defending against GUI confusion attack

Put Everything Together



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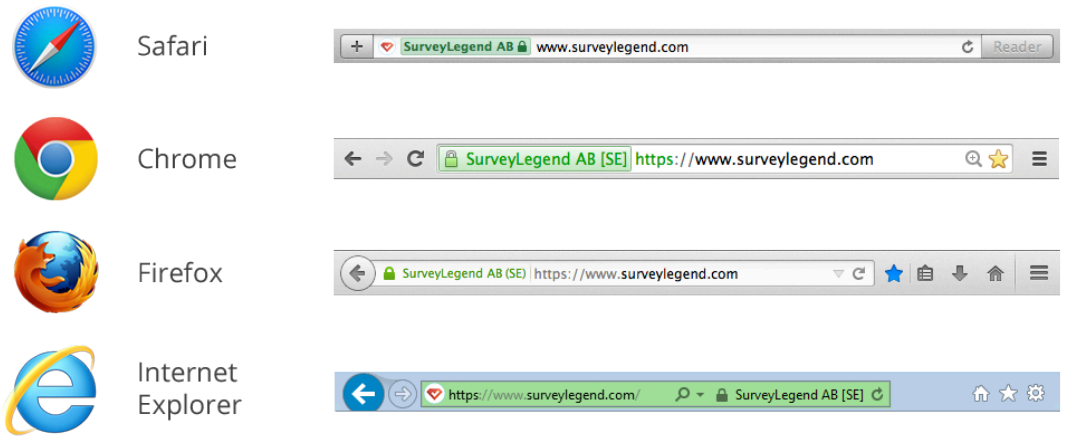

Extended Validation green address bar in modern browsers

App identity indicator in Android

Legitimacy of Windows

Legitimacy of Future Windows

Criteria: the principal that launches (or resumes) a window must be either the display owner app or a white list of principals (e.g., system UI).

Legitimacy of Existing Windows

Criteria: no existing windows should be placed on top of the display owner's window, unless it is from a white list of principals

Performance

- We evaluate the performance of WindowGuard by a comparison study.
- We generate the same sequence of 5000 user events to 10 app w/ and w/o WindowGuard installed
- On average, Windowguard incurs 0.8% performance overhead.