26TH USENIX
SECURITY SYMPOSIUM

# AWARE: Preventing Abuse of Privacy-Sensitive Sensors via Operation Bindings

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# Increasing Availability of Privacy-Sensitive Sensors

Controlling when **applications** may use **privacy-sensitive sensors** (i.e., cameras, microphones, and touch screens):

**Entertainment**

**Screen Sharing**

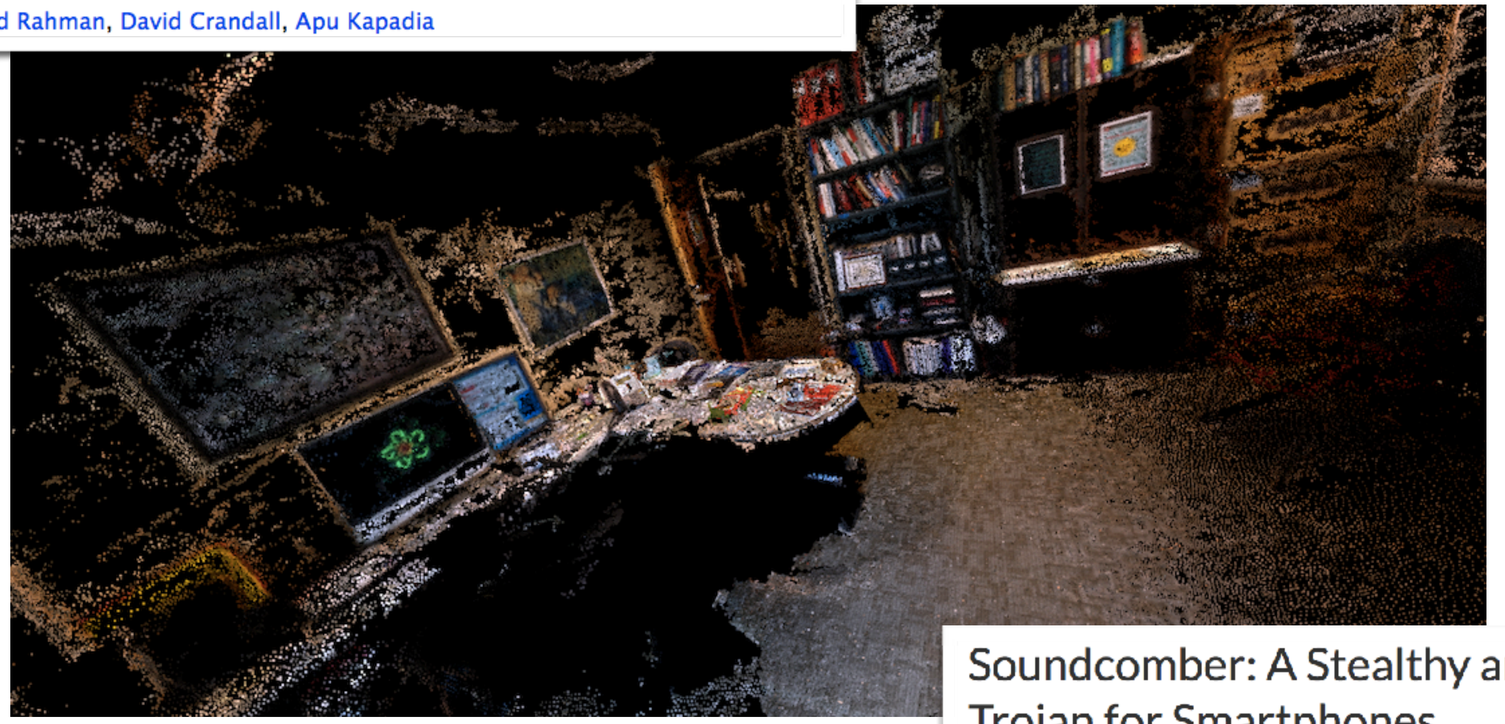
**Banking**

# Abuse of Privacy-Sensitive Sensors

PennState

**PlaceRaider: Virtual Theft in Physical Spaces with Smartphones**

Robert Templeman, Zahid Rahman, David Crandall, Apu Kapadia



Soundcomber: A Stealthy and Context-Aware Sound Trojan for Smartphones.

*Schlegel, Roman and Zhang, Kehuan and Zhou, Xiao-yong and Intwala, Mehool and Kapadia, Apu and Wang, XiaoFeng*

# Real World Incidents

Symantec discovered a new HTTP Android Remote administration tool, named Dendroid, available on the underground market for only $300.

## $610K Settlement in School Webcam Spy Case

Comments / Share / Tweet / Stumble / Email

Last February, the Lower Merion School District outside Philadelphia came under fire for using laptop webcams to look in on students at home. Last week, the school district settled legal action stemming from those actions.

## Krysanec trojan: Android backdoor lurking inside legitimate apps

BY ROBERT LIPOVSKY POSTED 12 AUG 2014 - 12:21PM

## Lawsuit claims popular Warriors app accesses phone's microphone to eavesdrop on you

By Katie Dowd, SFGATE Updated 3:13 pm, Thursday, September 1, 2016

SAN FRANCISCO — Want to invisibly spy on 10 iPhone owners without their knowledge? Gather their every keystroke, sound, message and location? That will cost you $650,000, plus a $500,000 setup fee with an Israeli outfit called the NSO Group. You can spy on more people if you would like — just check out the company's price list.

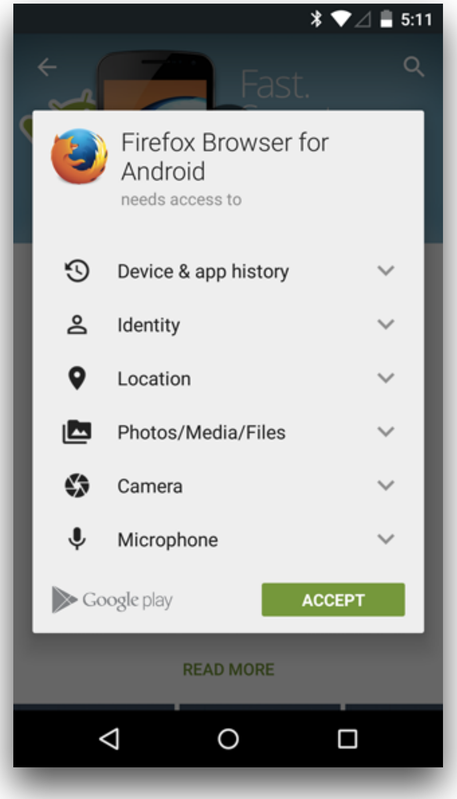
## FTC Issues Warning Letters to App Developers Using 'Silverpush' Code

**Letters Warn Companies of Privacy Risks In Audio Monitoring Technology**

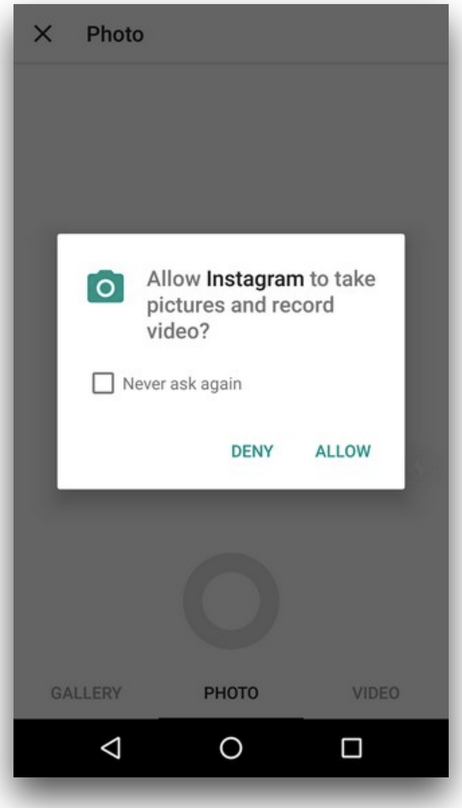
# Current Authorization Mechanisms

PennState

## Install-Time

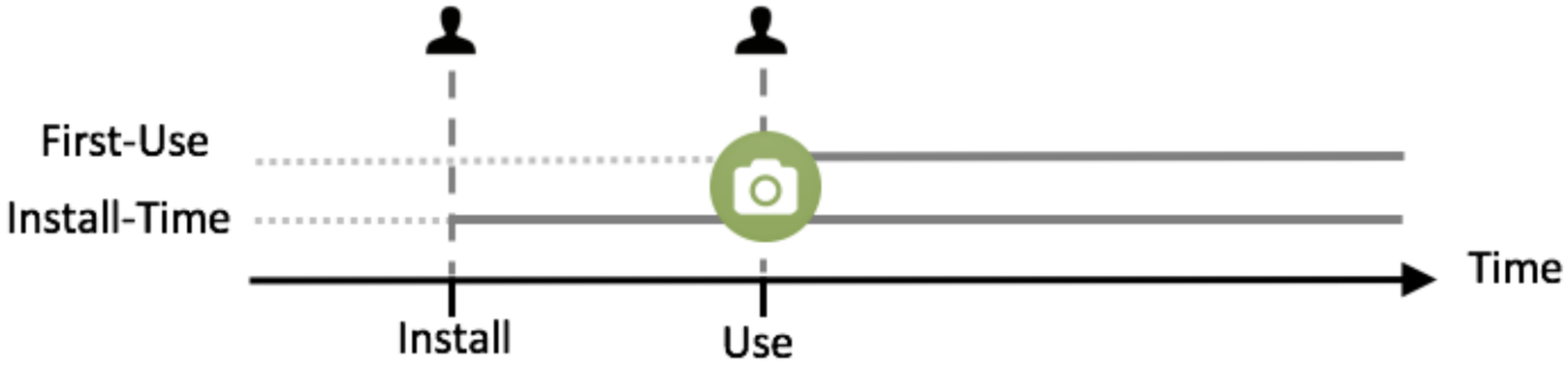



## First-Use

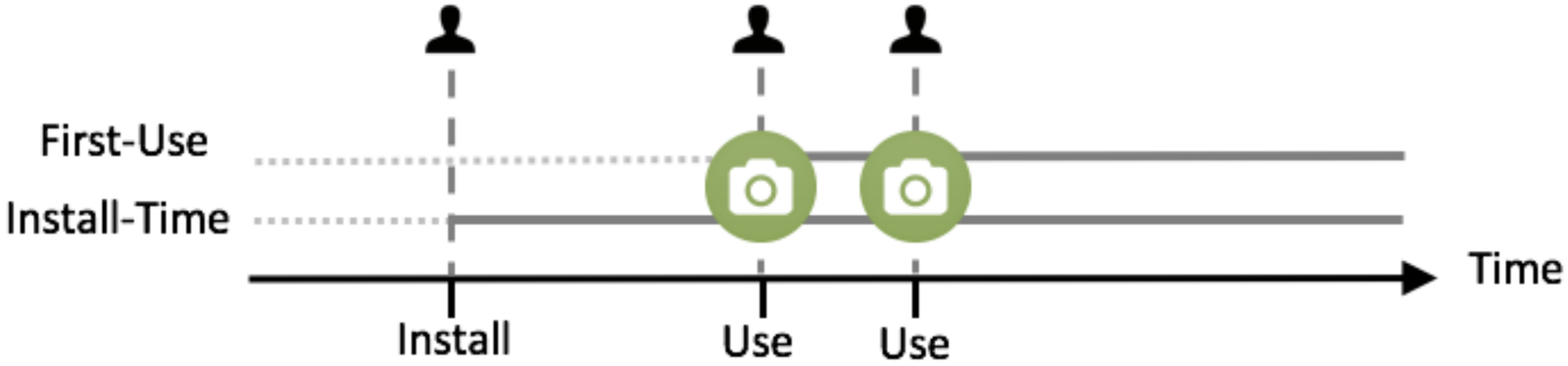



Beginning in Android 6.0 (API level 23), users grant permissions to apps while the app is running, not whey the install the app!

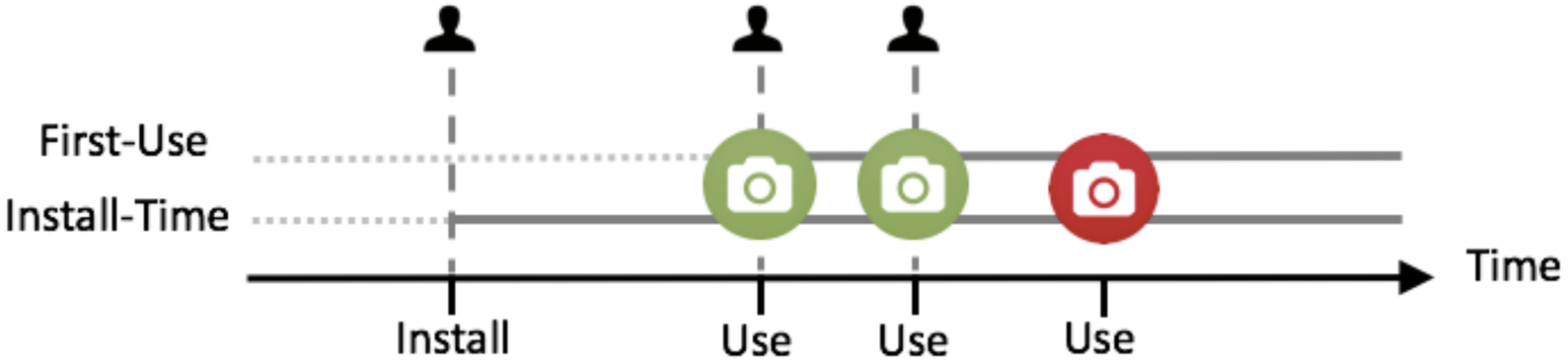
# Shortcomings



# Shortcomings



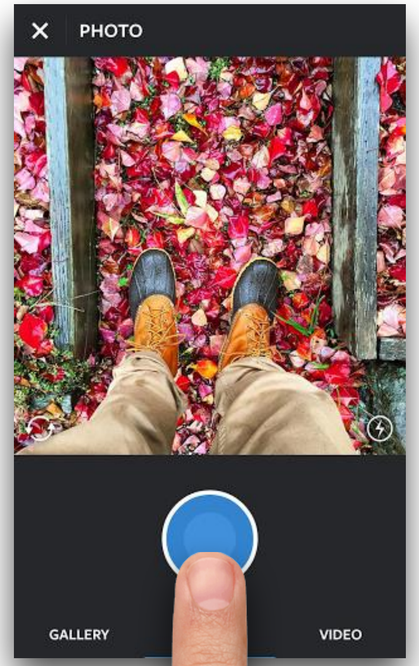
# Shortcomings



# Proposed Defenses

## Input-Driven Access Control (IDAC)

Authorize an operation request that immediately follows a user input event




**Overhaul**: **Input-Driven** Access Control for Better Privacy on Traditional Operating Systems
K Onarlioglu, W Robertson… - Dependable Systems and …, 2016 - ieeexplore.ieee.org

User inputs associated with operation authorizations

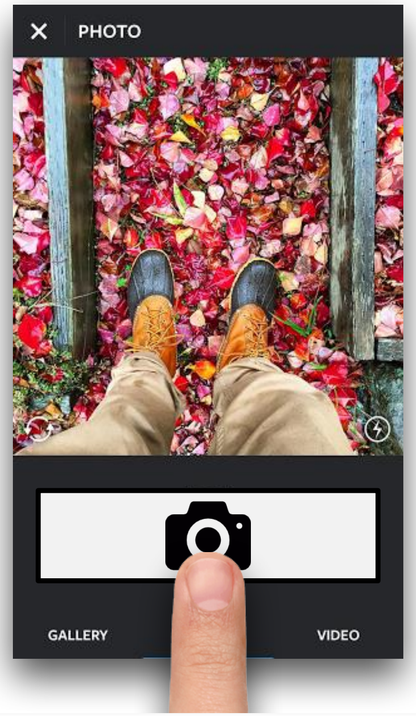
Binding between the user inputs and the authorized operations still unknown to the system!

# Proposed Defenses

## User-Driven Access Control (UDAC)

Applications must use **system-defined gadgets**

associated with particular operations




**Audacious**: User-driven access control with unmodified operating systems
T Ringer, D Grossman, F **Roesner** - Proceedings of the 2016 ACM ..., 2016 - dl.acm.org

**User-driven access control**: Rethinking permission granting in modern operating systems
F Roesner, T Kohno, A Moshchuk... - Security and privacy ..., 2012 - ieeexplore.ieee.org

Binding between the user input and the authorized operation explicit to the system

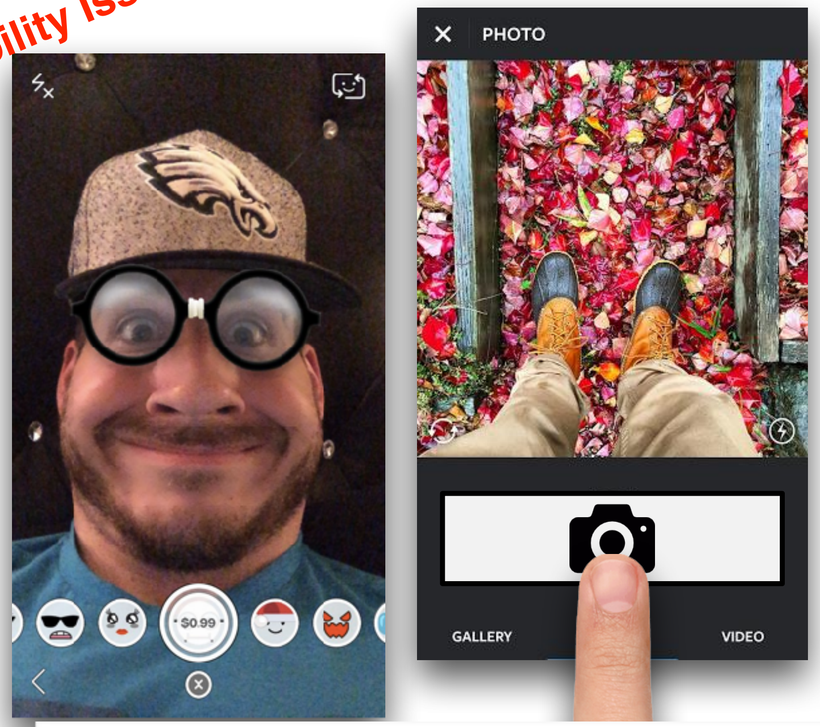
Binding still not explicit to the user!

# Proposed Defenses

## User-Driven Access Control (UDAC)

Applications must use system-defined gadgets associated with particular operations

Compatibility Issue

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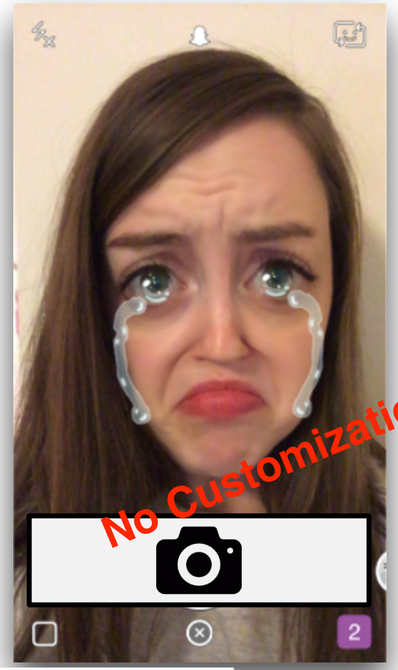
# Proposed Defenses

## User-Driven Access Control (UDAC)

Applications must use system-defined gadgets associated with particular operations

300,000+ apps
Need Redesign




No Customization

**Audacious**: User-driven access control with unmodified operating systems
T Ringer, D Grossman, F **Roesner** - Proceedings of the 2016 ACM …, 2016 - dl.acm.org

**User-driven access control**: Rethinking permission granting in modern operating systems
F Roesner, T Kohno, A Moshchuk… - Security and privacy …, 2012 - ieeexplore.ieee.org

# Limitations of Prior Work

Leverage the **user as weak link** to circumvent protection mechanisms!

**“User Interface Attacks”**

User may fail to:

- **Identify the application** requesting sensor access
- **Recognize subtle changes** in the Graphic User Interface (GUI)
- **Understand the operation** granted by a particular gadget

# Use Interface Attacks (Bait-and-Switch)

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Interaction #1

# Use Interface Attacks (Bait-and-Switch)

Interaction #2

# Use Interface Attacks (Bait-and-Switch)

Interaction #3

# Use Interface Attacks (Bait-and-Switch)

PennState

Interaction #4

# Use Interface Attacks (Bait-and-Switch)

Interaction #5

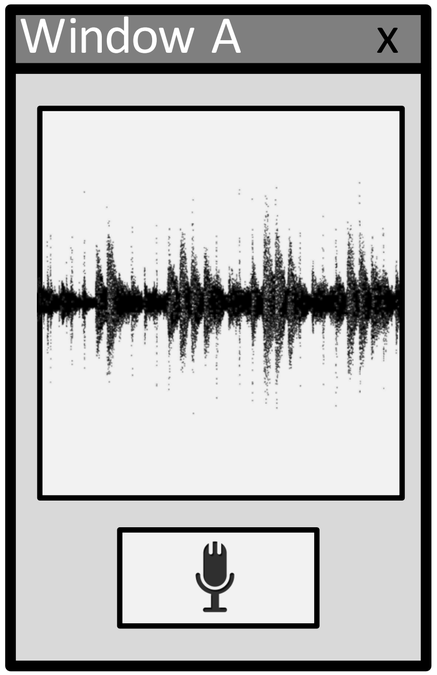
# Use Interface Attacks (Bait-and-Switch)

**Interaction #4**

The application maintained the windowing display context but switched the widget to **record audio**

**“Bait-and-Switch Attack”**

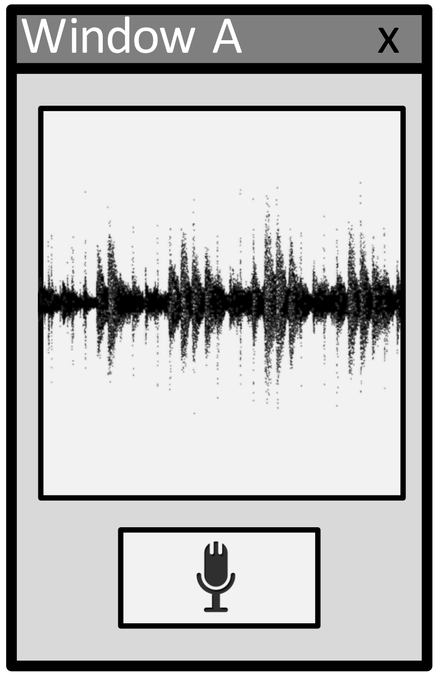
# Use Interface Attacks (Application Spoofing)




Google

A click by the user allows
the **Legitimate App**
to record audio

# Use Interface Attacks (Application Spoofing)




MR. ROBOT

A click by the user allows
the **Spoofing App**
to record audio

**"Application Spoofing Attack"**

# Research Objectives

- **Operation authorizations explicit to both the system and the user**
- **Compatible with pre-existing applications**
- **Low authorization effort for the user** (~ First-Use)
- **No perceivable performance overhead**

**AWARE**: Authorization Framework extending OS middleware
to make access to privacy-sensitive sensors **explicit** to both the system and the user

# Challenge: Identify legitimate entry points (Widgets)

**Goal**: Identify the app's widgets available to the user for requesting access to privacy-sensitive sensors

# Challenge: Identify legitimate entry points (Widgets)

**Insight**: Bind each user input even with the application's widget displayed on the screen

*Operation Binding*

(***app, e, w***)

*app* = application associated with widget

*e* = user input event

*w* = user interface widget

# Challenge: Identify legitimate UI configurations for Widgets

**Goal**: Identify the particular user interface configuration within which each widget is allowed to appear on the screen

# Challenge: Identify legitimate UI configurations for Widgets

PennState

**Insight**: Bind the widget with a set of structural features that uniquely identify the UI configuration

*Operation Binding*

(*app*, *e*, *w*, ***c***)

*app* = application associated with widget

*e* = user input event

*w* = user interface widget

*c* = user interface configuration containing the widget

# Challenge: Constrain the App Requests

**Goal**: Make the application's requested operation and the target sensors explicit to the system

# Challenge: Constrain the App Requests

**Insight**: Mediate each application's operation request and identify the privacy-sensitive sensors targeted by such operation. Bind the application's request to a specific input event for a particular widget.

*Operation Binding*

(*app*, ***S***, ***op***, *e*, *w*, *c*)

*app* = application associated with widget and operation request

*S* = set of sensors targeted by the request

*op* = operation being requested

*e* = user input event

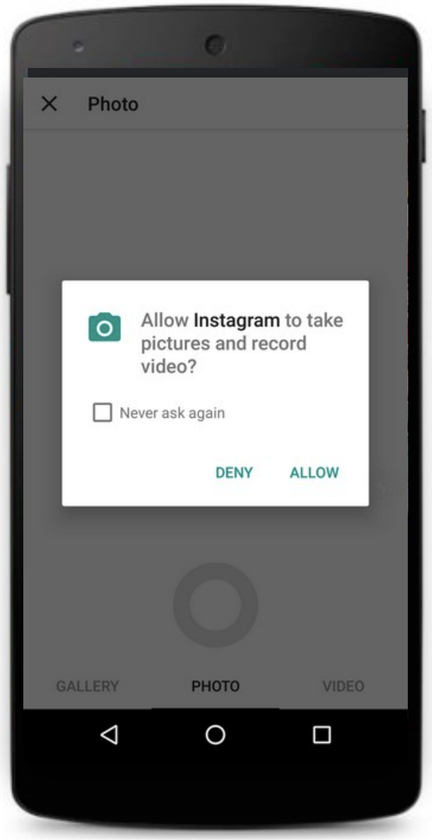
*w* = user interface widget

*c* = user interface configuration containing the widget

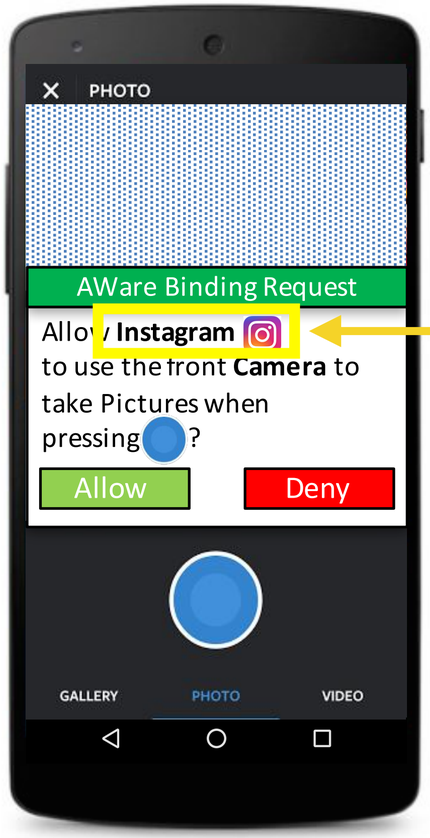
# Challenge: Make the Operation Binding explicit to the user

**Currently**

**(First-Use)**



# AWARE's Explicit Binding Request

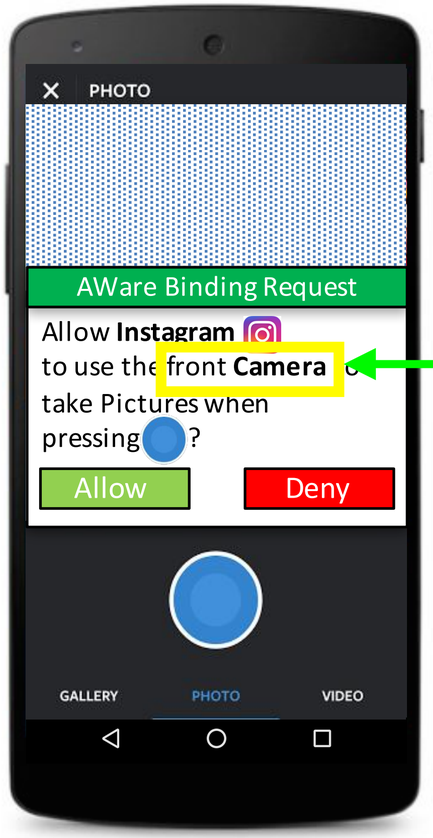



app (Application ID)

(***app***, *S*, *op*, *e*, *w*, *c*)

**are now explicit!**

# AWARE's Explicit Binding Request



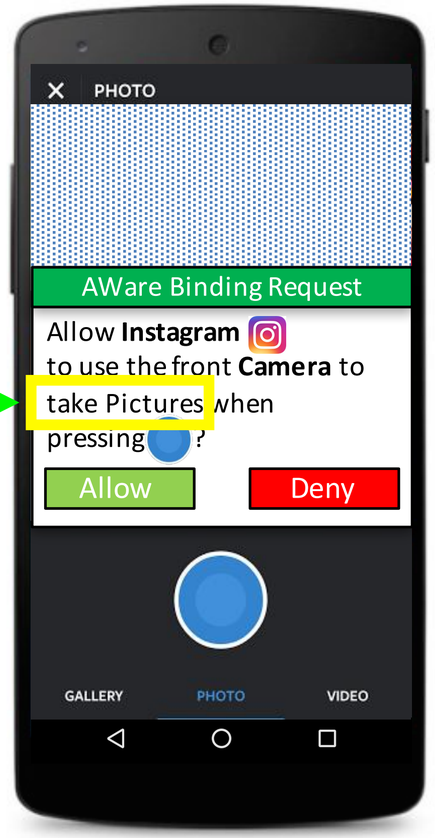

S (Set of Sensors)

(*app*, ***S***, *op*, *e*, *w*, *c*)

**are now explicit!**

# AWARE's Explicit Binding Request

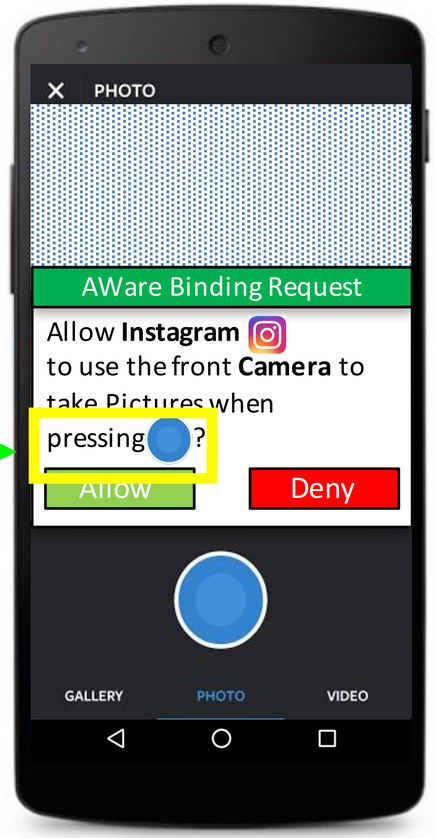
**op**
**(Requested Operation)**




(*app*, *S*, ***op***, *e*, *w*, *c*)

**are now explicit!**

# AWARE's Explicit Binding Request



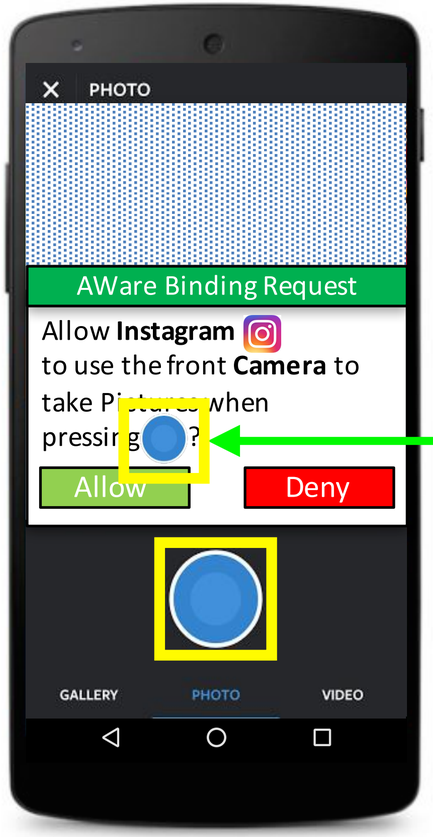

**e**

**(Input Event)**

(*app*, *S*, *op*, ***e***, *w*, *c*)

**are now explicit!**

# AWARE's Explicit Binding Request

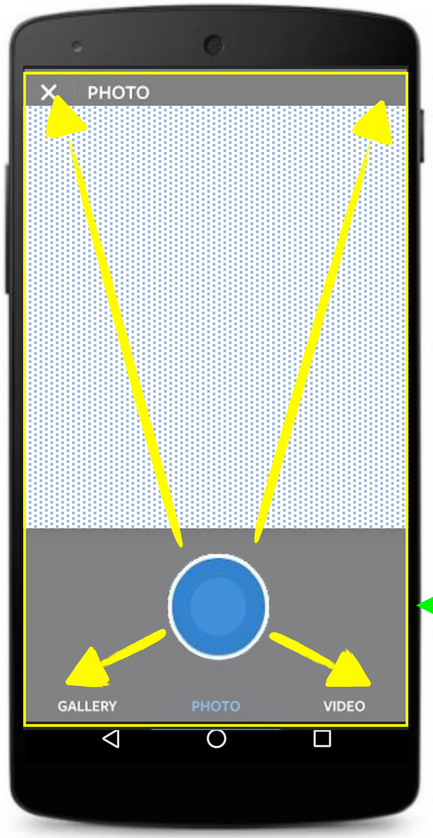



w (Widget)

(*app*, *S*, *op*, *e*, ***w***, *c*)

**are now explicit!**

# AWARE's Explicit Binding Request




← **c (UI Configuration)**

(*app*, *S*, *op*, *e*, *w*, ***c***)

**are now explicit!**

# Challenge: Limit User Effort

**Goal**: Limit the number of **Explicit Authorization** required by the User!

# Challenge: Limit User Effort

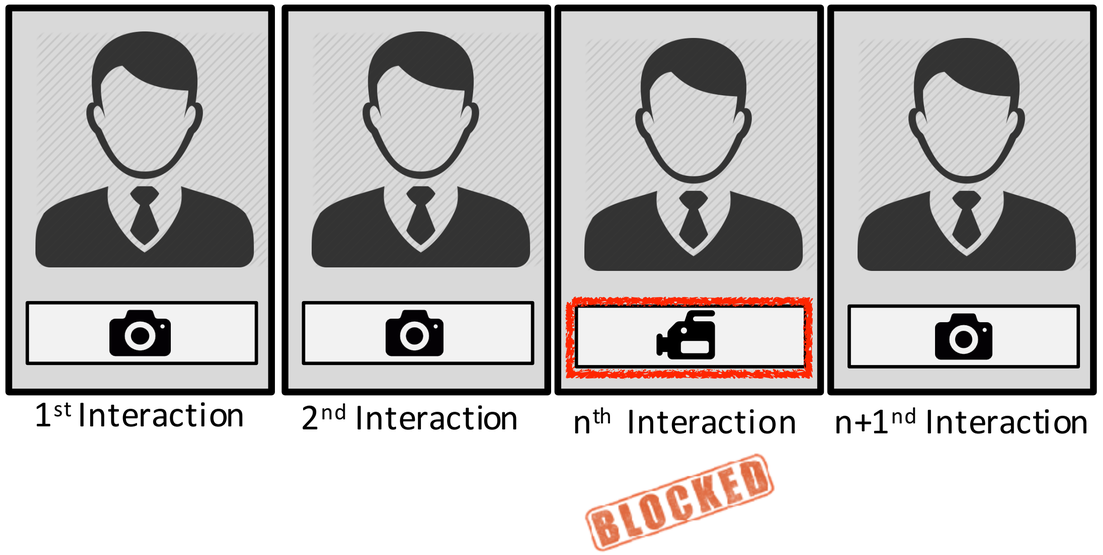
**Insight**: Cache Operation Bindings!

A user's authorization of an operation binding implies that:

*"The application will be allowed to perform the **requested operation** on the **set of sensors***

*whenever the user produces the **same input event** using the **same widget** within the **same user interface configuration**"*

# Preventing Bait-and-Switch Attacks



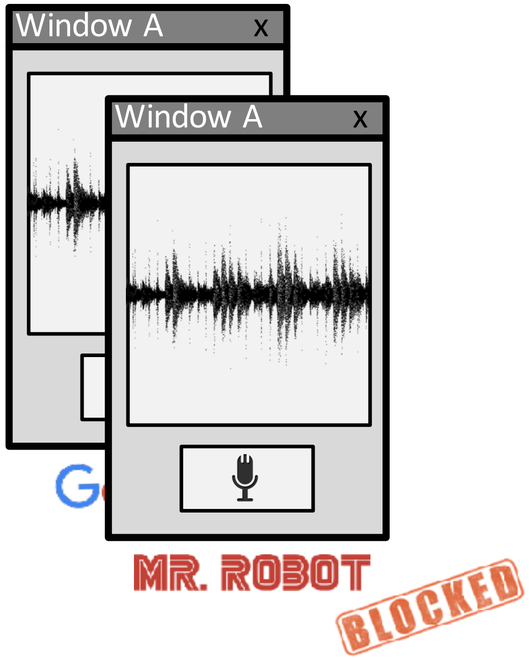

## *Operation Binding*

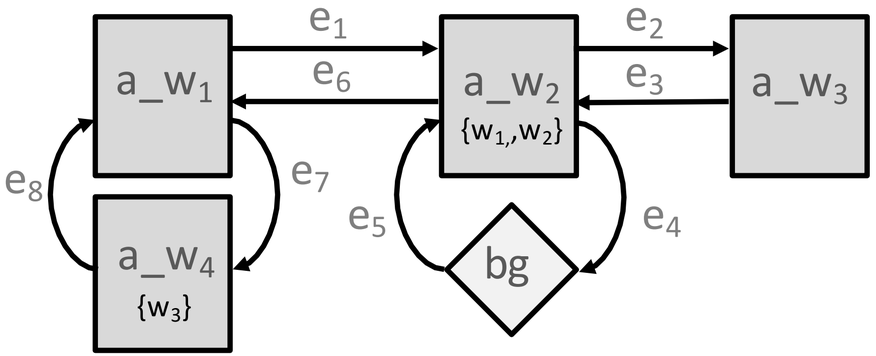
(*app*, *S*, *op*, *e*, ***w***, ***c***)

### *Display Context*

c = set of structural Features of the most enclosing activity window containing the widget w

# Preventing Application Spoofing Attacks



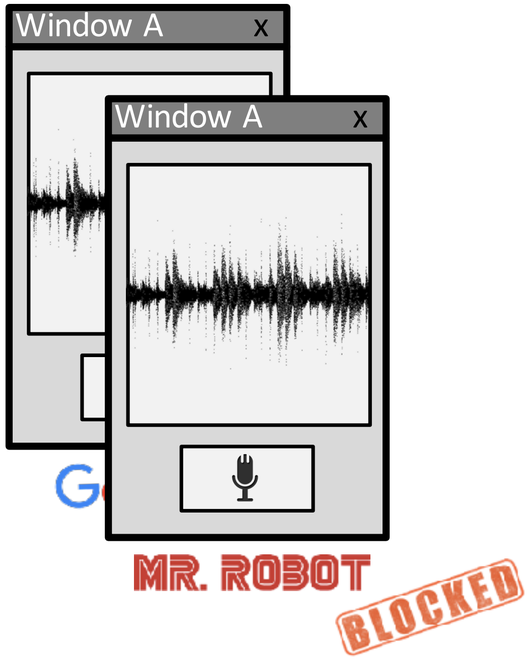

***Activity Window Call Graph***

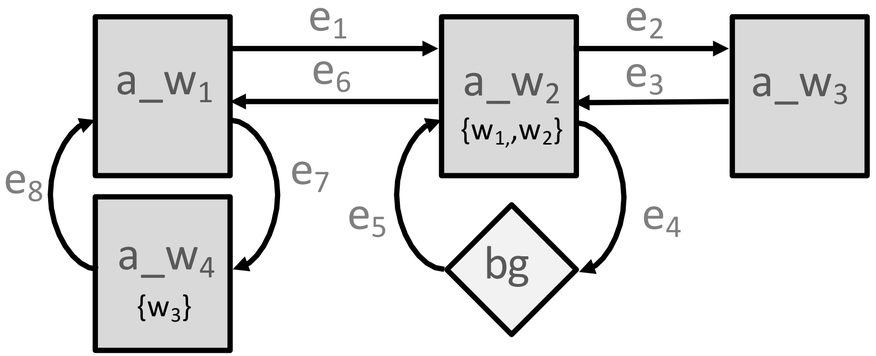
Nodes represent activity windows

Edges represent enabled transitions

(user input or system events)

# Preventing Application Spoofing Attacks



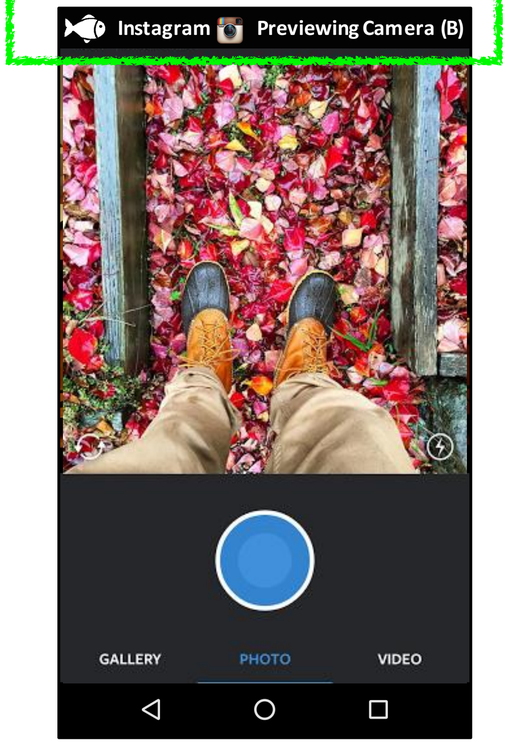

***Activity Window Call Graph***

Nodes represent activity windows

Edges represent enabled transitions

(user input or system events)

**Security Message**




***Operation Binding***

(***app***, ***S***, ***op***, *e*, *w*, *c*)

# Experimental Evaluation

**Prototyped** (Android OS 6.0.1_r5)

**Tested** (Nexus 5 and Nexus 5X smartphones)

**Research Questions**:

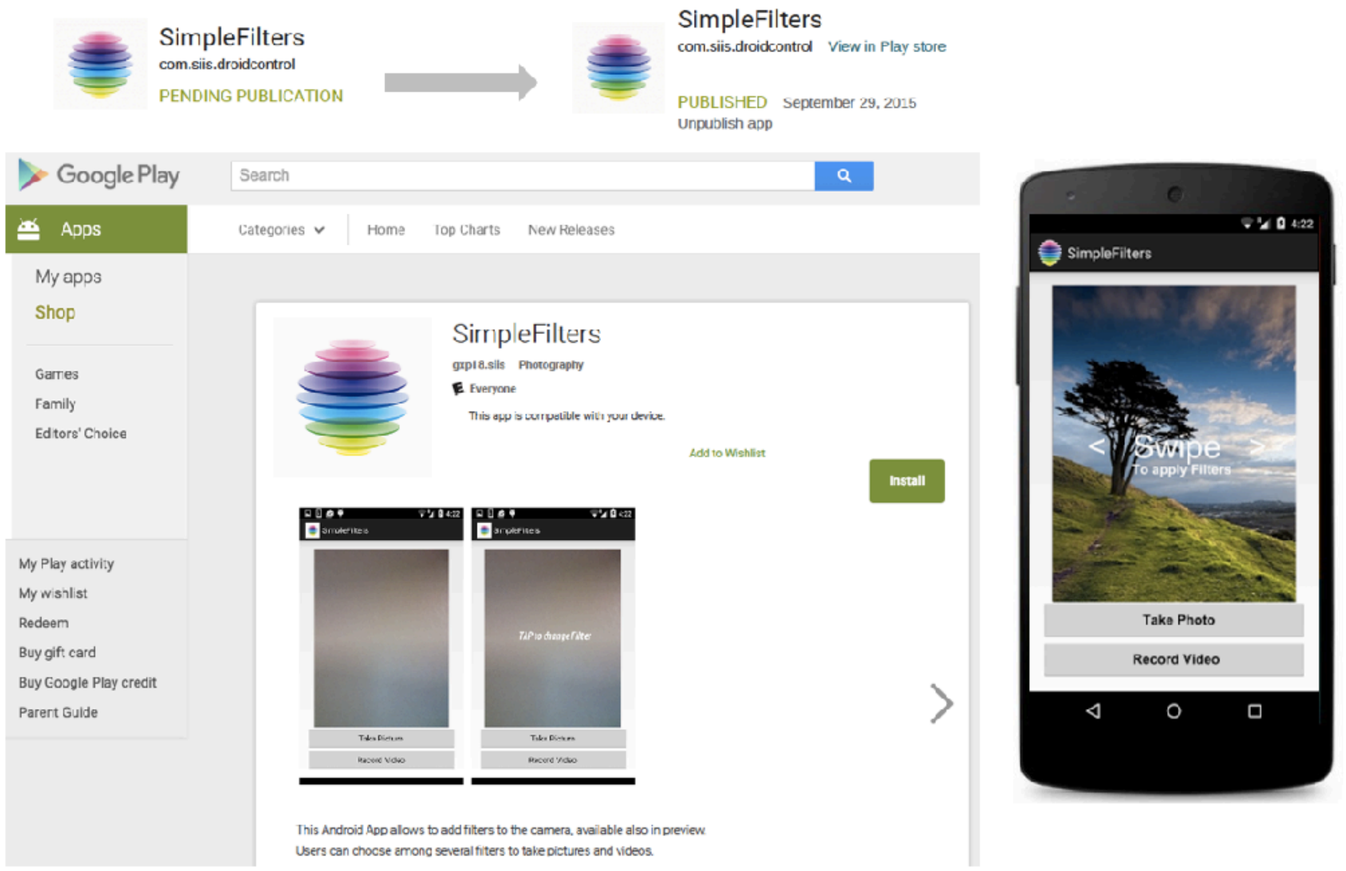
- *To what degree is the **AWARE** operation binding concept assisting the users in avoiding attacks?* (**Effectiveness**)
- *What is the decision overhead imposed to users due to per-configuration access control?* (**Usability**)
- *How many existing apps malfunctioned due to the integration of **AWARE**?* (**Compatibility**)
- *What is the performance overhead imposed by **AWARE** for the operation binding construction and enforcement?* (**Performance**)

# Effectiveness

*To what degree is the **AWARE** operation binding concept assisting the users in avoiding attacks?*

**Laboratory-Based User Study** (90 Participants)

Groups: Install-Time, First-Use, Input-Driven, System-Defined Gadgets, and **AWARE**



# Effectiveness

*To what degree is the **AWARE** operation binding concept assisting the users in avoiding attacks?*

**Laboratory-Based User Study** (90 Participants)

Groups: Install-Time, First-Use, Input-Driven, System-Defined Gadgets, and **AWARE**

| Task Description (Randomized) | Attack Scenario |
|---|---|
| **TASK 1** : Take a picture with the smartphone's front camera by using the `SimpleFilters` app. | Operation Switching: The `SimpleFilters` app also starts recording audio via the smartphone's microphone instead of only taking a picture. |
| **TASK 2** : Take a picture with the front camera by using the `SimpleFilters` app. | Bait-and-Context-Switch: We make the video camera widget appear in the photo capture window, with a camera preview, to trick the user into allowing `SimpleFilters` to record audio instead of just take a picture. □ |
| **TASK 3** : Take six consecutive pictures with the smartphone's front camera by using the `SimpleFilters` app. | Bait-and-Widget-Switch: Before the participants took the fifth picture, the `SimpleFilters` app replaced the camera widget with the video camera widget to enable video recording instead. The camera button was restored before the users took the sixth picture. □ |
| **TASK 4** : Record a voice note using the `Keep` app. | Identity Spoofing: We let the participants select the `Keep` app from the app menu, however, we programmatically triggered the `SimpleFilters` app to hijack the on-screen activity and spoof the `Keep` app. |

# Effectiveness

*To what degree is the **AWARE** operation binding concept assisting the users in avoiding attacks?*

Experimental Results:

- TASK 1: Operation performed by app not visible (Exception for Access Control Gadgets)
  Attack Prevention Rate: **Others 2%** vs **AWARE 100%**

- TASK 2 and TASK 3: Users were successfully tricked by switching the user interface configuration!
  Attack Prevention Rate: **Others 2%** vs **AWARE 93%**

- TASK 4: Real identity of the app performing the operation was not visible to users
  Attack Prevention Rate: **Others 6%** vs **AWARE 100%**

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# Usability

*What is the **decision overhead** imposed to users due to per-configuration access control?*

**Field-Based User Study** (24 Participants)

- 21 apps (7 categories)*
- 1 week

(Comparison with First-Use)

4 explicit authorizations per-application on average

| App Category | App Name | Explicit User Authorizations | | Total Operation Authorizations |
|---|---|---|---|---|
| | | First-Use | AWARE | Avg. (s.d.) |
| Audio Recording | WhatsApp | 3 | 6 (±1) | 1,217 (±187) |
| | Viber | 1 | 1 (±1) | 88 (±9) |
| | Messenger | 3 | 7 (±2) | 2,134 (±176) |
| Photo and Video Recording | Facebook | 2 | 4 (±1) | 3,864 (±223) |
| | SilentEye | 2 | 5 (±1) | 234 (±20) |
| | Fideo | 2 | 4 (±1) | 213 (±23) |
| Screenshot Capture | Ok Screenshot | 1 | 2 (±1) | 49 (±8) |
| | Screenshot Easy | 1 | 2 (±1) | 76 (±7) |
| | Screenshot Capture | 1 | 2 (±1) | 64 (±4) |
| Screen Recording | REC Screen Recorder | 2 | 3 (±1) | 41 (±8) |
| | AZ Screen Recorder | 2 | 4 (±2) | 49 (±7) |
| | Rec. | 2 | 3 (±1) | 66 (±4) |
| Full Screen Mode | Instagram | 2 | 6 (±1) | 3,412 (±182) |
| | Snapchat | 2 | 6 (±1) | 5,287 (±334) |
| | Skype | 2 | 9 (±3) | 468 (±62) |
| Remote Control | Prey Anti Theft | 2 | 8 (±2) | 47 (±5) |
| | Lost Android | 2 | 6 (±1) | 37 (±6) |
| | Avast Anti-Theft | 2 | 4 (±1) | 34 (±7) |
| Hands-Free Control | Google Voice Search | 1 | 1 (±1) | 1,245 (±122) |
| | HappyShutter | 1 | 1 (±0) | 3 (±1) |
| | SnapClap | 1 | 1 (±0) | 4 (±2) |

*www.statistica.com

# Compatibility

*How many existing apps malfunctioned due to the integration of **AWARE**?*

**Android Compatibility Test Suite** (CTS):

- 1,000 apps (Google Play)
- 13 hours and 28 minutes

Experimental Results:

- **126,681 passed** tests over **126,686**
- [**Viber**] Camera and microphone probing at reboot (No impact on video or voice calls)

# Performance

*What is the **performance overhead** imposed by **AWARE** for the operation binding construction and enforcement?*

**Android UI/Application Exerciser Monkey**:

- 1,000 app (Google Play)
- Nexus 5 and Nexus 5X

Microbenchmark:

- Access requests for operation targeting privacy-sensitive sensors
- 10,000 operations

Experimental Results:

- **0.33%** system-wide **performance overhead**
- About **3 MB of cache** for operation binding cache and window call graphs

# Conclusion

- Authorization of sensor operations *explicit* to both system and user (**Operation Binding**)
  Up to 100% **user interface attack prevention** (only up to 6% with alternative approaches)
- **Low user effort** (**Caching of Bindings** when UI is same for same operation)
  4 explicit authorizations per-application on average
- **Compatible with pre-existing applications** (**No app modification or redesign**)
  Only 5 minor compatibility issues out of 1,000 tested apps
- **Negligible Performance Overhead** (limited number of authorization hooks and quick retrieval of bindings)
  0.33% performance overhead and 3 MB of cache

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# Thank You
# For Your Attention!


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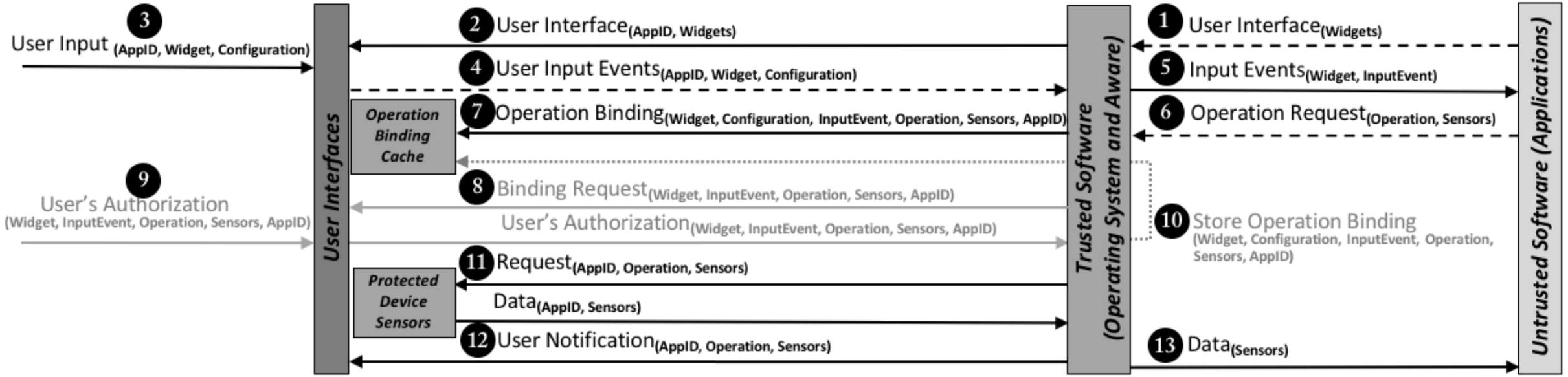
**Source Code**: https:/github.com/gxp18/AWare


**Research Funded by:**

ARL

# Approach Overview

PennState

## AWARE Authorization Workflow