Cloak & Dagger

From Two Permissions to Complete Control of the UI Feedback Loop

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joint work with
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Black Hat USA 2017
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Who am I?

- PhD candidate @ UC Santa Barbara
  - Graduating in a week!
  - Shellphish Hacker
  - Soon Assistant Professor at Eurecom, France!

- Research focus on mobile security
  - Program analysis, rowhammer attacks (Drammer), ultrasound cross-device tracking, UI attacks

- When I don’t procrastinate, I’m on twitter @reyammer
What is this work about?

- A few tricks to attack Android UI
- Complete control over the UI feedback loop
- Bye bye to your device’s security
UI Feedback Loop

Know what is currently displayed to the user

Modify what the user sees

Output channel

Know what the user is clicking on

Inject user input

Input channel

Cloak & Dagger Attacks
Why should I care about UI bugs? ACADEMIC BS!

- Android features tons of low-level security mechanisms
  - Sandboxing & permissions
  - Exploit mitigation techniques
  - Attack surface reduction

- Some UI bugs can bypass all low-level mechanisms
  - If you can click like a user...confused deputy!
  - “Dear Settings app, I hope this request finds you well.
    Would you mind granting me all permissions? Thx <3”

BH USA 2017 talk
“Honey, I shrunk the attack surface – Adventures in Android security hardening”
(by Nick Kralevich)

Good stuff!
Two Permissions
Run-time Granting Permissions

Apps targeting Android SDK level 23 or higher
SYSTEM_ALERT_WINDOW ("draw on top")

- Draw arbitrary windows/overlays on top of the screen
  - Can be completely custom: shape, content, transparency
  - Can be clickable xor passthrough

- This permission is used quite often
  - 454 out of 4,455 top apps (10.2%)

- Used by Facebook, Skype, Uber, LastPass, ...
BIND_ACCESSIBILITY_SERVICE (a11y)

- Mechanism for apps to assist users with disabilities

- Many powerful capabilities
  - It is notified for each UI event
  - It can inject UI events (e.g., clicks)

- Several security mechanisms to avoid abuse

- Used by 24 top apps out of 4,455
  - Password managers (LastPass), antivirus apps, app lockers, ...
These two permissions are enough to completely compromise your device.
Why would a user grant these permissions?

- “The user needs to explicitly approve! Not stealthy!”

- “Draw on top” is automatically granted for Play Store apps!

- We developed a new practical clickjacking attack
  - The user is lured to unknowingly enable the a11y!

The list of permissions is not even shown!
The user needs to explicitly approve! Not stealthy!

- "The user is lured to unknowingly enable the a11y!"
- "Draw on top" is automatically granted for Play Store apps!
- We developed a new practical clickjacking attack
- The list of permissions is not even shown!

Why would a user grant these permissions?

- The user needs to explicitly approve!
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Security Mechanisms
Security Mechanism #1

- For each click on an overlay, only one of these holds:
  1) The click is “captured” by the overlay
     - The overlay knows when/where the user clicked
  2) The click goes “through” the overlay
     - The click reaches what’s “behind” it
     - The overlay does not know when/where the user clicked

- No “capture & propagate” click

- Why?
Security Mechanism #1
Security Mechanism #1

- One possible attack: FLAG_WATCH_OUTSIDE_TOUCH
  - An overlay can receive events even for clicks that land outside itself

- The click coordinates are set to (0,0) if the click does not reach the app that created the overlay
Security Mechanism #2

- Several steps are required to enable accessibility service
Security Mechanism #2

[Images of an accessibility settings menu and a tutorial app setting]
Security Mechanism #3

- Protection against clickjacking
Clickjacking 101

UI Redressing Attacks on Android Devices Revisited
Niemietz & Schwenk
BH ASIA 2014
Security Mechanism #3

- Protection against clickjacking

- Google introduced the “obscured” flag
  - When the user clicks on a widget, FLAG_WINDOW_IS_OBSCURED is set if “an overlay was covering the receiving widget”
  - An app can decide to “not trust” the click

- Another option: setFilterTouchesWhenObscured()
Security Mechanism #3

Use Tutorial App?
Tutorial App needs to:

- **Observe your actions**
  Receive notifications when you're interacting with an app.

- **Retrieve window content**
  Inspect the content of a window you're interacting with.

CANCEL  OK

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CANCEL  OK

Because an app is obscuring a permission request, Settings can't verify your response.
Security Mechanism #3

“Because an app is obscuring a permission request, Settings can’t verify your response.”
Security Mechanism #4

- Accessibility service cannot read “sensitive information” off the screen.
- Example: password fields

“Since an event contains the text of its source privacy can be compromised by leaking sensitive information such as passwords. To address this issue any event fired in response to manipulation of a PASSWORD field does NOT CONTAIN the text of the password.”
Unleashing Mayhem
Attack: Context-aware Clickjacking

- Multi-stage clickjacking are challenging
  - When to transition to the next stage?
  - What if the user clicks “somewhere else”?

- Security mechanisms
  - The malicious app is not notified about the clicks
  - If the FLAG_WATCH_OUTSIDE_TOUCH is used, the click’s coordinates are set to (0,0) if click lands on another app: where did the user clicked?

- What if there is only “one way” for a click to not reach the malicious app?
Attack: Context-aware Clickjacking

- We know the user clicked on the “target” button
- We know we need to transition to the next step
Obscured Flag Bypass

- The “obscured” flag is helpful to detect that “another overlay is on top”

- Who says that you need to cover the “target” widget?
Obscured Flag Bypass

Capture?  OK

Context-Hiding Attack
Attack: Context Hiding

- Design shortcoming: Apps do not have access to enough context information to take informed decisions

- The “obscured flag” is conceptually broken

- Difficult to fix:
  - If the full context is exposed, an attacker could (ab)use this information as side channel to mount phishing attacks
Context-aware clickjacking + Context hiding

- These two attacks are enough to lure the user to enable the accessibility service!

- We just need to hijack three clicks
  - No guessing is involved
  - The clicks do not need to be consecutive
Back to the “obscured flag”...

- Not only it is not useful…

- ...but #1: misleading documentation
“This flag indicates that the window that received this motion event is **partly** or wholly obscured by another visible window above it.”
/**
 * This flag indicates that the window that received this motion event is partly
 * or wholly obscured by another visible window above it. This flag is set to true
 * even if the event did not directly pass through the obscured area.
 * A security sensitive application can check this flag to identify situations in which
 * a malicious application may have covered up part of its content for the purpose
 * of misleading the user or hijacking touches. An appropriate response might be
 * to drop the suspect touches or to take additional precautions to confirm the user's
 * actual intent.
 *
 * Unlike FLAG_WINDOW_IS_OBSCURED, this is actually true.
 * @hide
 */

public static final int FLAG_WINDOW_IS_PARTIALLY_OBSCURED = 0x2;
same as FLAG_WINDOW_IS_OBSCURED

"Unlike FLAG_WINDOW_IS_OBSCURED, this is actually true."
Back to the “obscured flag”...

- Not only it is not useful…
- ...but #1: misleading documentation
- ...but #2: it can be abused to mount even worse attacks!
Attack: Invisible Grid Attack

- This attack can record all “keystrokes”
  - It only relies on the “draw on top” permission

- It abuses the “obscured flag” security mechanism
Attack: Invisible Grid Attack

Where did the user click?

Overlays are drawn:
- Invisible
- Clicks passthrough
- FLAG_WATCH_OUTSIDE_TOUCH

The “obscured” flag is set accordingly!

Overlay #
1. MotionEvent
2. MotionEvent
3. MotionEvent
4. MotionEvent
Attack: Invisible Grid Attack

Overlays are drawn
- Invisible
- Clicks passthrough
- FLAG_WATCH_OUTSIDE_TOUCH

The “obscured” flag is set accordingly!

Overlay #
- 1: MotionEvent Not obscured
- 2: MotionEvent Not obscured
- 3: MotionEvent Not obscured
- 4: MotionEvent Not obscured

Where did the user click?
Attack: Invisible Grid Attack

Overlays are drawn
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- FLAG_WATCH_OUTSIDE_TOUCH

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Overlay #

1. MotionEvent
   - Obscured

2. MotionEvent
   - Not obscured

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4. MotionEvent
   - Not obscured

Where did the user click?
Attack: Invisible Grid Attack

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1  MotionEvent  Obscured
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- Invisible
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Overlay #

1. MotionEvent Obscured
2. MotionEvent Obscured
3. MotionEvent Obscured
4. MotionEvent Not obscured
Attack: Invisible Grid Attack

Security mechanism used as side-channel!

The attacker can use these patterns to infer where the user clicked!
Attack: Invisible Grid Attack

These overlays are drawn invisible during a real attack.
Design Shortcomings

- The inherent complexity of the Android “WindowManager” leads to the creation of unexpected side channels
  - UI security as an afterthought

- Violation of the principle of least privilege
  - Why can an app create *invisible* overlays? *Passthrough* overlays?
  - Overlays are **completely** customizable!
Attack: a11y on steroids

- Yet another design shortcoming:
  - By default, UI objects are all considered non-security sensitive
  - Security should be the rule, not the exception!
Attack: a11y on steroids

1) Steal PIN
2) Inject PIN and unlock the phone!

Bonus point: phone unlock while keeping the screen off!
Cloak & Dagger attacks

- You can mount even nastier attacks by combining the two permissions!
Traditional Phishing
Traditional Phishing

Didn’t I click login???
Attacks: Stealthy Phishing

Fill by a11y

Clicked by a11y

UI-in-the-middle Attack

Welcome, John!

Great!
Attack: Silent God-mode App Installation

- We show a video to the user...

- ...and, behind the scene, we do nasty things via a11y

- The grand plan
  - Silent installation of super-malicious app
  - Enable all its permissions
  - Clean up steps
Additional Attack Scenarios

- Ransomware!
  - Block device by changing the PIN to an attacker-controlled one

- Covering and clicking around on Chrome
  - Taking over victim’s Google account
  - Steal saved passwords, etc

- Note: even if Google fixes its apps, third-party apps will remain vulnerable to these attacks
Clickjacking ~> a11y & Silent God-mode App Install
Ransomware Example
Are these attacks actually practical?
User Study

- 20 human subjects (all from Georgia Tech)

- Attacks we tested
  - Clickjacking to enable a11y
  - Silent God-mode App Installation
  - Stealthy Phishing
Results

- **Clickjacking to enable a11y**
  - None of the subject understood what happened

- **Silent God-mode App Installation**
  - None of the subject understood what happened

- **Stealthy Phishing**
  - 18 out of 20 did not detect any difference
  - The remaining two triggered a bug in our prototype, and they reported “graphical glitches” (but they did not understand they were attacked)
Overall Awareness

- Do users know about these two permissions?

- Results are worrisome
  - Only 2 out of 20 knew about the “draw on top” permission
  - Only 5 out of 20 knew about a11y
  - *No subject knew about both!*

- ...why should they look for them?
How can we fix this?
Responsible Disclosure

- “Simple bugs” via AOSP reports (August 22nd, 2016)
  - Invisible Grid Attack ~> Moderate severity (not fixed yet)
  - A11y on steroids ~> ???
Disclosure of “a11y on steroids” (August 22nd)

- Bug marked as “Won’t fix, work as intended” (September 30th)

- Bug marked as “High severity” (October 18th)

- Downgraded to “Won’t fix” because “limiting those services would render the device unusable” (November 28th)

- “We will update the documentation” (May 4th)

- AND THEY DID!!!11!1!
a11y documentation “patch”

- AccessibilityEvent’s “security note” is silently removed
  - [June 6th version](#) vs [current version](#)

- “Patch the documentation, not the code”

- 0day in the documentation! Where is my CVE?! :-)


Responsible Disclosure

- “Simple bugs” via AOSP reports (August 22nd, 2016)
  - Invisible Grid Attack ~> Moderate severity
  - A11y on steroids ~> ???
  - New clickjacking technique
Few classes of vulnerabilities will generally not qualify for a reward:
- **Tap-jacking** and **UI-redressing** attacks that involve tricking the user into tapping a UI element
"BUT, BUT, BUT...."
Responsible Disclosure

- “Simple bugs” via AOSP reports (August 22nd, 2016)
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  - A11y on steroids ~> ???
  - New clickjacking technique ~> :-(

- Shared the paper draft with Adrian Ludwig, head of Android security (December 19th)
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**All attacks are still working!**
(Even on Android 7.1.2, with July’s updates)
How is the Android security team reacting?

UI ATTACKS?
THAT'S CUTE

PANIC!!!
“I’m not alone”

- UI security is not considered a “big deal”

- Check Nick Kralevich’s talk at Android Security Symposium, March 2017 (https://youtu.be/ITL6VHOFOj8?t=57m40s)
  - First question during the Q&A...
UI security is not considered a “big deal”

“There are also plain boring bugs, for example in the UI [...], personally I don’t report them anymore because you just don’t care. My bugs are hanging with the ‘new’ status for years then they are just auto-closed.”

“I’m not alone”
“I’m not alone”

- UI security is not considered a “big deal”

  “There are also plain boring bugs, for example in the UI [...], personally I don’t care. My bugs are in the ‘new’ status for years then they are just auto-closed.”
Securing Android UI

- Introduce the concept of “Secure Apps & Widgets”
  - Defined through a flag that is propagated across the view tree

- OS-enforced guarantee
  - No overlay will be shown on top of any secure app/widget

- System popups
  - Inspired by web popups
Introduce the concept of “Secure Apps & Widgets”
- Defined through a flag that is propagated across the view tree

OS-enforced guarantee
- No overlay will be shown on top of any secure app/widget

System popups
- Inspired by web popups
What happened next...

- Work presented at IEEE Security & Privacy 2017
  - Distinguished Practical Paper award!

- We setup a website and tweeted about it

- Crazy amount of press coverage…
“[...] We have updated Google Play Protect — our security services on all Android devices with Google Play — to detect and prevent the installation of these apps. Prior to this report, we had already built new security protections into Android O that will further strengthen our protection from these issues moving forward.”
Detect Cloak & Dagger

- What would I do?
  - Detect apps that combine these two permissions

- Does the attacker really need both permissions?

- Eh eh...
Bootstrap the attacks from one permission

- Start with an app that only requires “SYSTEM_ALERT_WINDOW”

- Install a secondary malicious app that only requires a11y!

- How?
CLICKJACKING
EVERYWHERE
Clickjacking Everywhere!
Let’s go one step further...

- ...do we actually need the SYSTEM_ALERT_WINDOW?
Let’s go one step further...

- SYSTEM_ALERT_WINDOW permission is needed to create windows of “TYPE_ALERT_SYSTEM”

- Realization: the attacker just needs to create windows on top of all apps’ activities
  - She does not need to go over “system” windows (e.g., status bar, navigation bar)
  - Any overlay’s “type” that goes on top of activities is enough
Toasts are usually created with this API:

- `makeText(Context context, int resId, int duration)`
- Duration: either 2 seconds or 3.5 seconds
- Limited customization capabilities
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- `makeText(Context context, int resId, int duration)`
- Duration: either 2 seconds or 3.5 seconds
- Limited customization capabilities

It is possible to create arbitrarily custom “Toasts”
- `TYPE_SYSTEM_ALERT` ~> `TYPE_TOAST`
- “Pretty simple” to port all the attacks
FTW!

- Toasts are usually created with this API:
  - `makeText(Context context, int resId, int duration)`
  - Duration: either 2 seconds or 3.5 seconds

```bash
sed -i "s/TYPE_SYSTEM_ALERT/TYPE_TOAST/" *
```

- Possible differences to look out for:
  - `TYPE_SYSTEM_ALERT` ~> `TYPE_TOAST`
  - “Pretty simple” to port all the attacks
Impact & Caveats

- Android 6.0.1
  - You can bootstrap Cloak & Dagger attacks with zero permissions
  - Caveat: you need to hijack two more clicks to install the app with a11y

- Android 7.1.2
  - Several mechanisms against Toast abuse
    - The SYSTEM_ALERT_WINDOW permission is required
  - You can bootstrap Cloak & Dagger attacks with one permissions
    - Same caveat as above
Android O (Preview 3 developer version)

- Invisible Grid Attack is fixed! YEAH!

- Clickjacking: currently more vulnerable than before
  - The final “OK” button to enable a11y is NOT protected by the obscured flag :-(

- “A11y on steroids” attacks “work as intended” ;-(
- Invisible Grid Attack is fixed! YEAH!

- Clickjacking: currently more vulnerable
  - The final “OK” button to enable a11y is NOT protected by the obscured flag :-(

- “A11y on steroids” attacks “work as intended” ;-)

Clickjacking ~> a11y seems fixed in Android O Preview 4!! (released few days ago :-))
Fixing clickjacking might be trickier than expected...
Fixing clickjacking might be trickier than expected...

An Android 6.0-only bug prevents granting permissions when Twilight is on (fixed in Android 7+).
Current state of Android security updates

<table>
<thead>
<tr>
<th>Device</th>
<th>No guaranteed Android version updates after</th>
<th>No guaranteed security updates after</th>
<th>No guaranteed telephone or online support after</th>
</tr>
</thead>
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<tr>
<td>Nexus 10</td>
<td>November 2014</td>
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</table>

Stuck with Android 6.0.1
## Current state of Android security updates

<table>
<thead>
<tr>
<th>Phone</th>
<th>No guaranteed Android version updates after</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Pixel XL</td>
<td>October 2018</td>
<td>October 2019</td>
<td>October 2019</td>
</tr>
<tr>
<td>Pixel</td>
<td>October 2018</td>
<td>October 2019</td>
<td>October 2019, $769</td>
</tr>
</tbody>
</table>

- Pixel XL: $769
- Pixel: $649
Takeaways

- “Cloak & Dagger” attacks
  - UI attacks are still a thing
  - Many low-level security mechanisms are bypassed

- UI security bugs matter
  - They are the low-hanging fruits for the attackers

- More info: cloak-and-dagger.org