TEL AVIV UNIVERSITY

Trust Dies in Darkness: Shedding Light on Samsung's TrustZone Cryptographic Design

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Extended paper: https://eprint.iacr.org/2022/208.pdf

Tool + PoC: https://github.com/shakevsky/keybuster

WHO WOULD WIN?

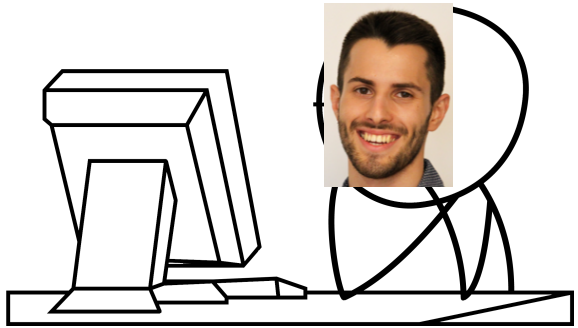
The leading Android Vendor

SAMSUNG

Common Criteria

FIPS LEVEL 1 VALIDATED FIPS

3 academic researchers



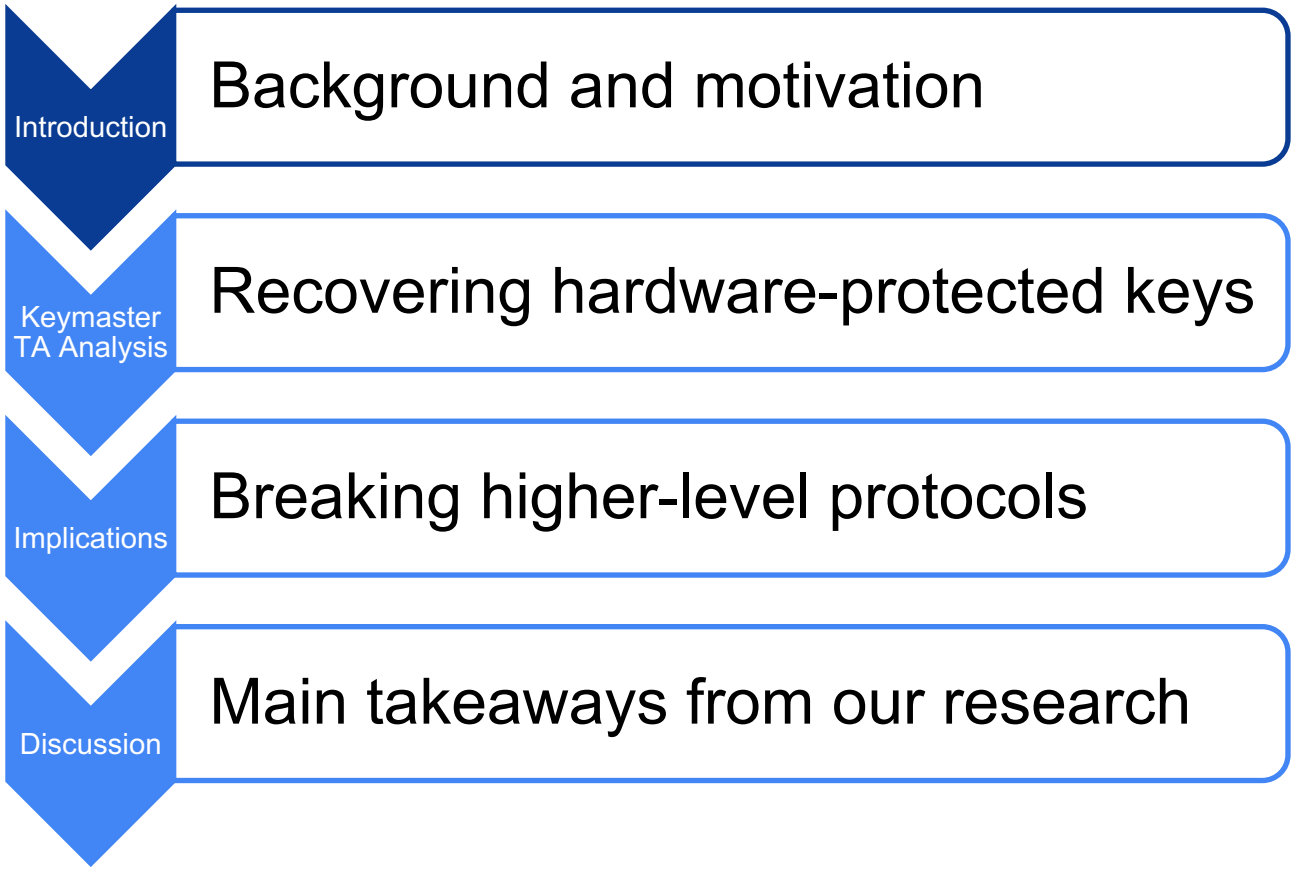
What did we find?

2 High severity CVEs that affect over 100 million devices

Recover keys that were encrypted by trusted hardware

Designed using resources from Flaticon.com

Agenda


Introduction
Background and motivation
Keymaster TA Analysis
Recovering hardware-protected keys
Implications
Breaking higher-level protocols
Discussion
Main takeaways from our research

The need for Trusted Execution Environments (TEEs)

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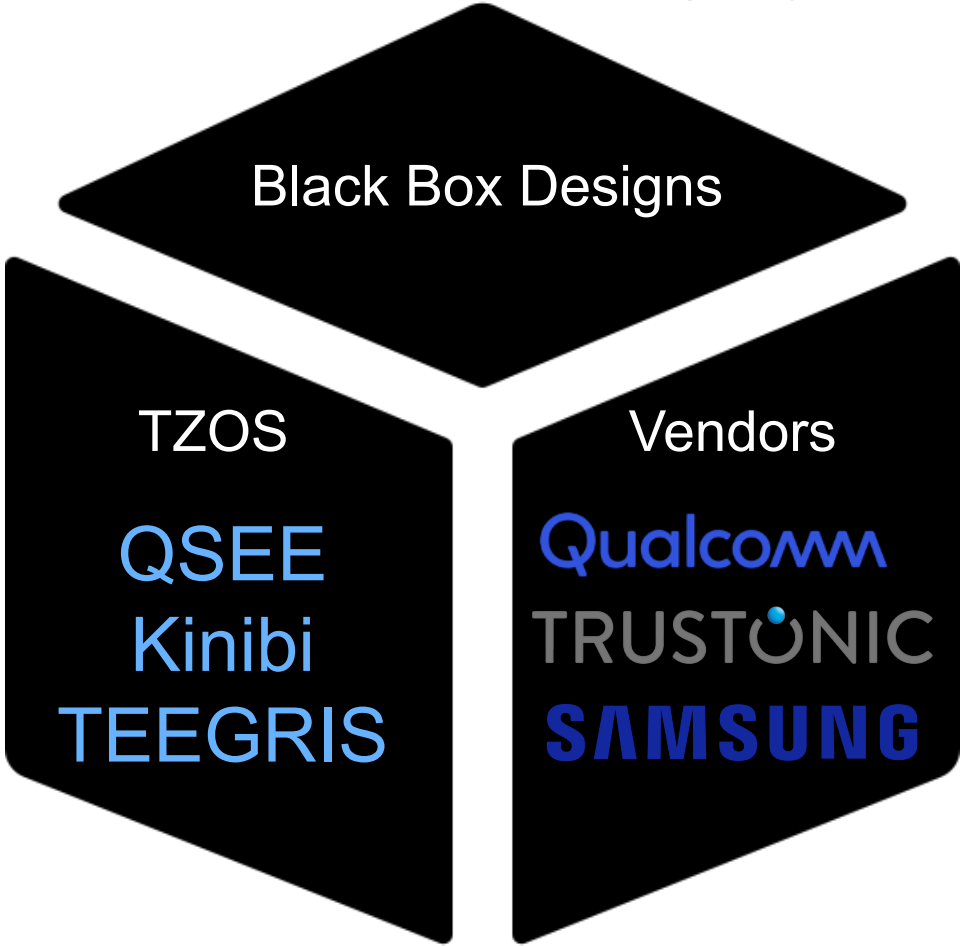
Proprietary TrustZone Operating Systems (TZOS)



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Research questions

1. Do hardware-protected cryptographic keys remain secure even when the Normal World (Android) is compromised?

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1. Do hardware-protected cryptographic keys remain secure even when the Normal World (Android) is compromised?
2. Do compromised hardware-protected keys break the security of various protocols that rely on them?

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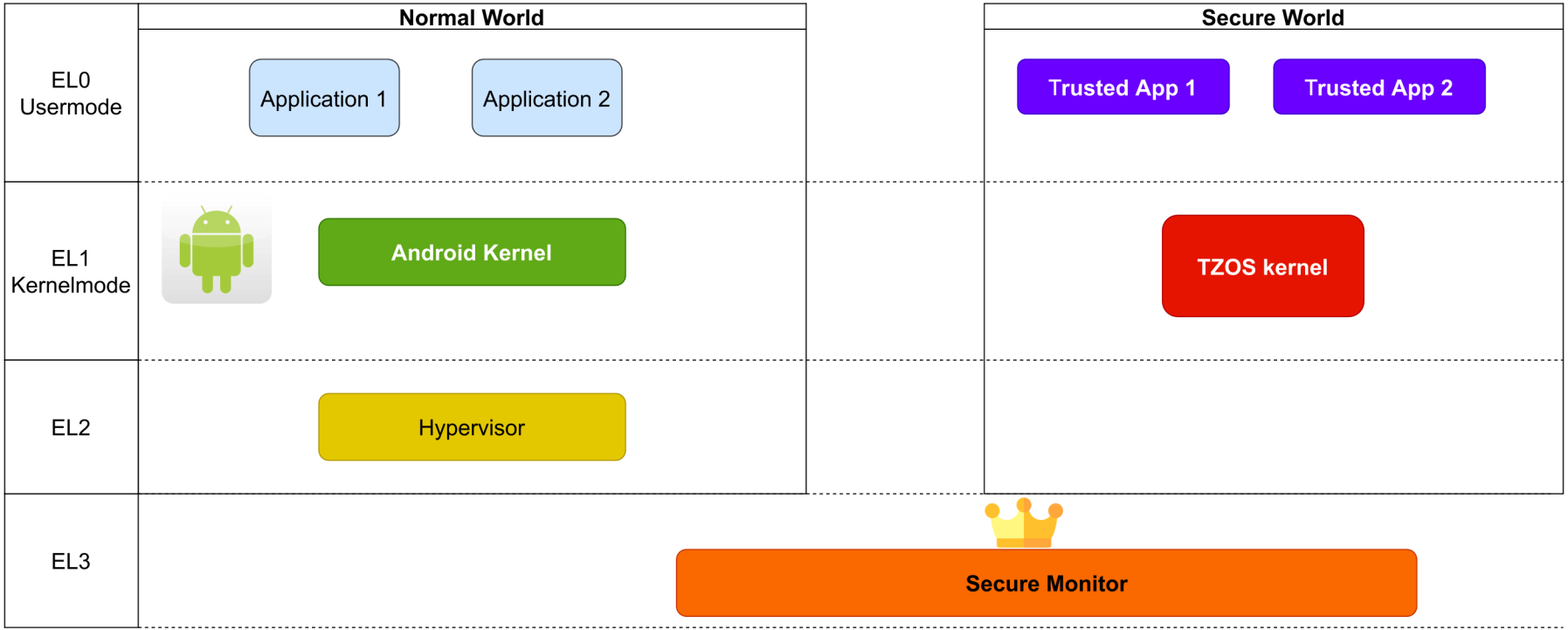
ARM TrustZone - Attack Model



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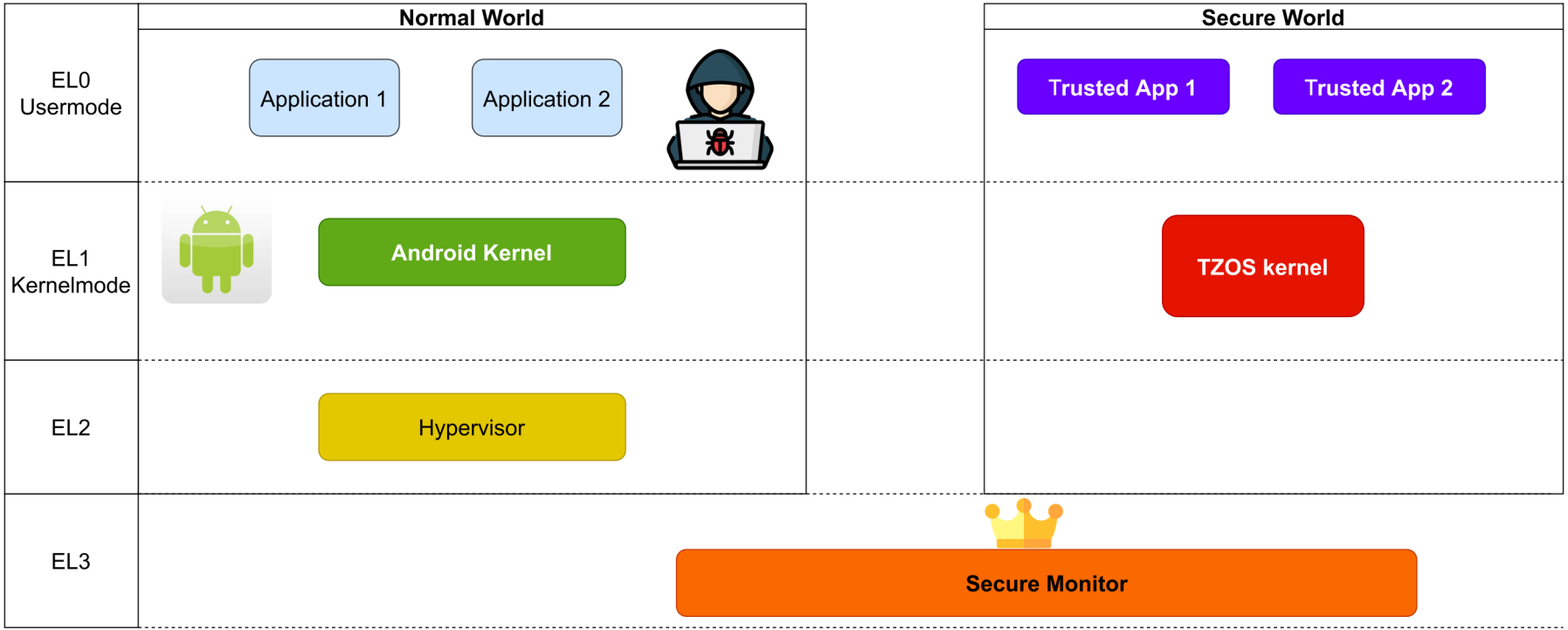

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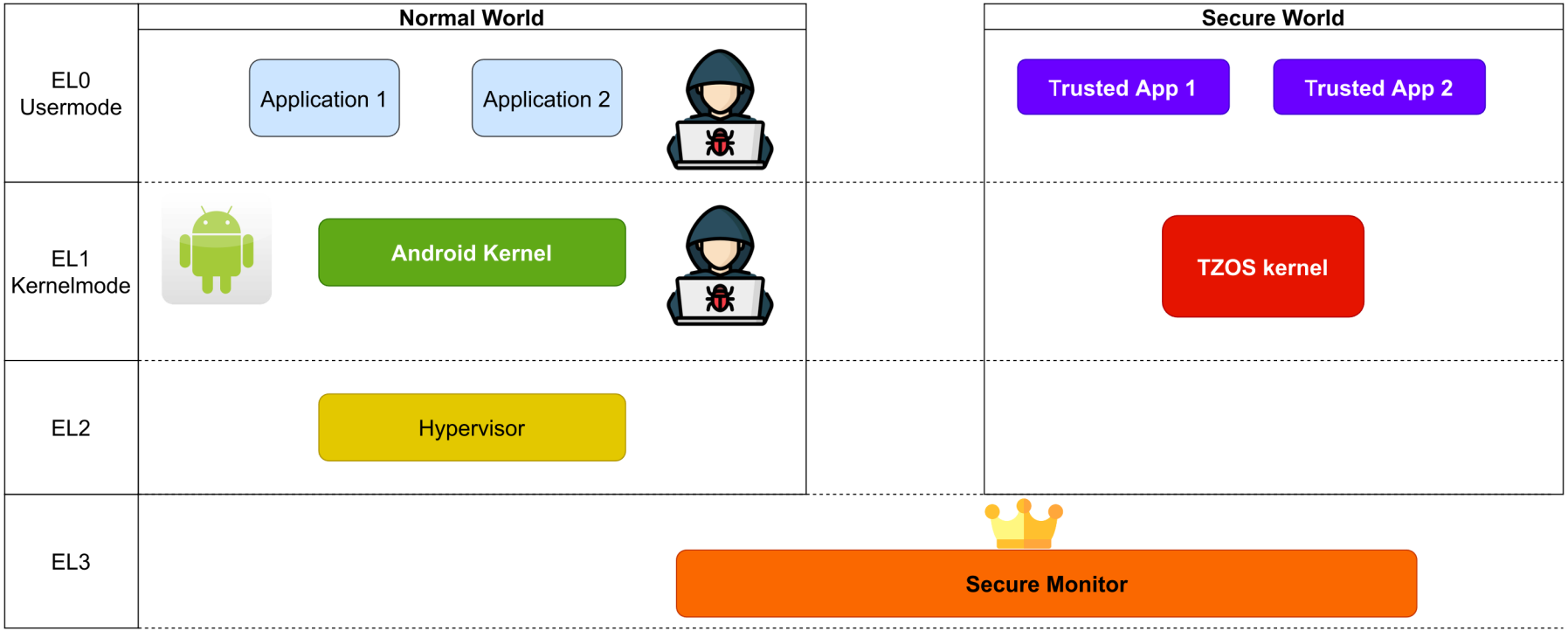

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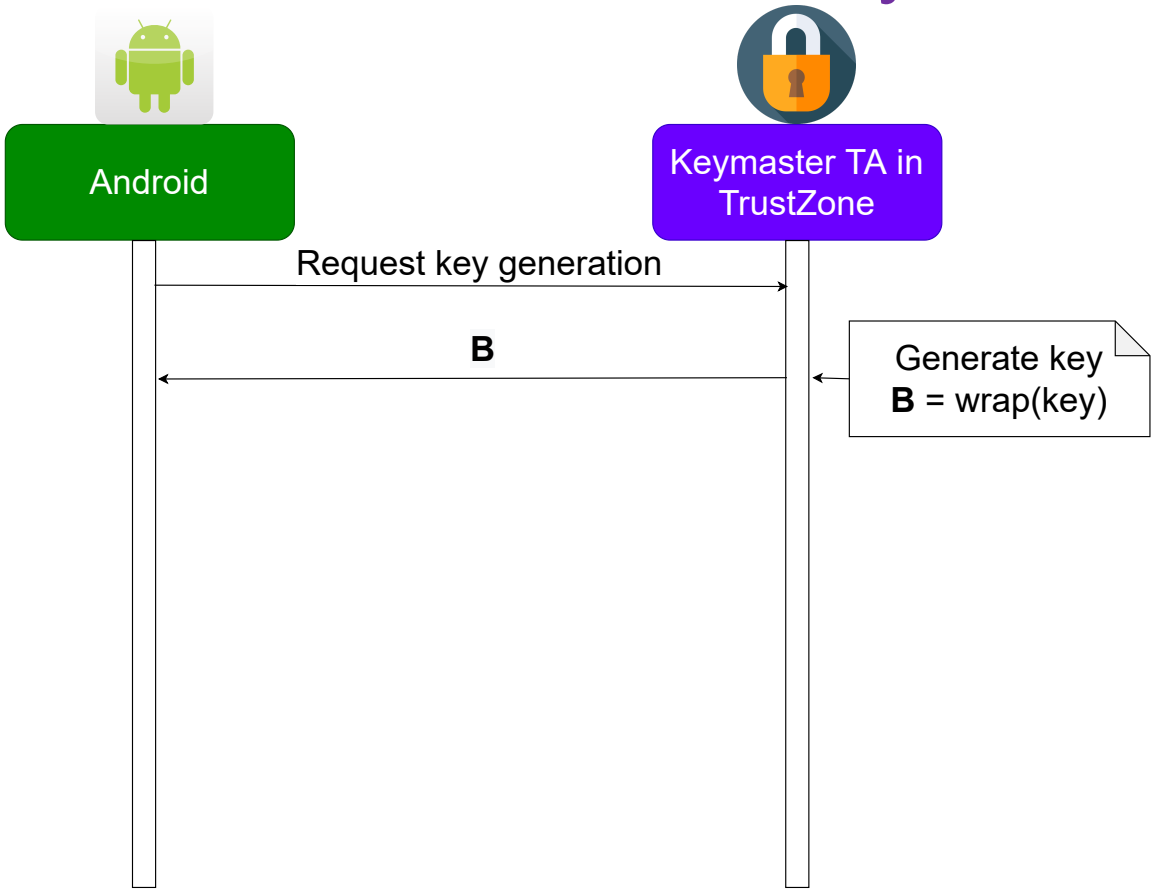
Android Hardware-Backed Keystore Flow



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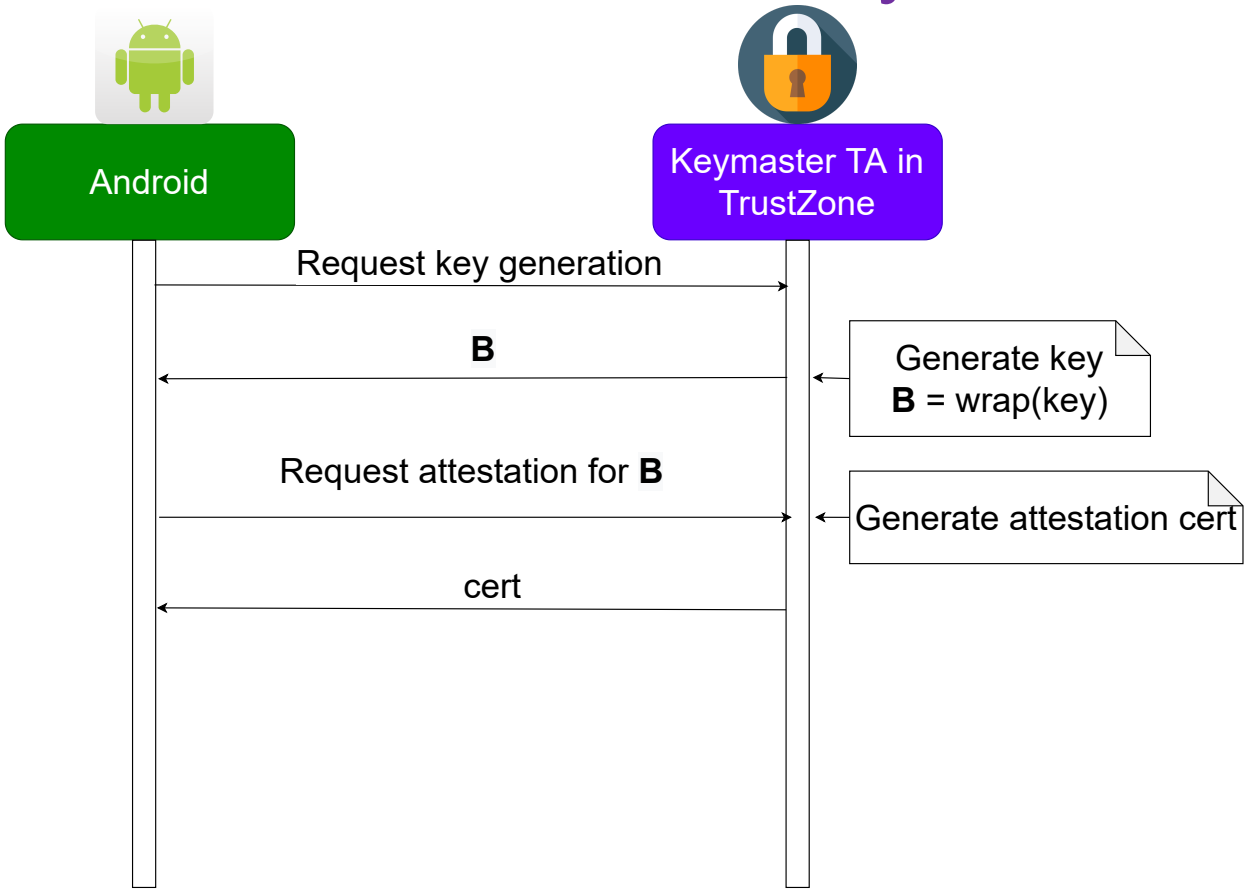

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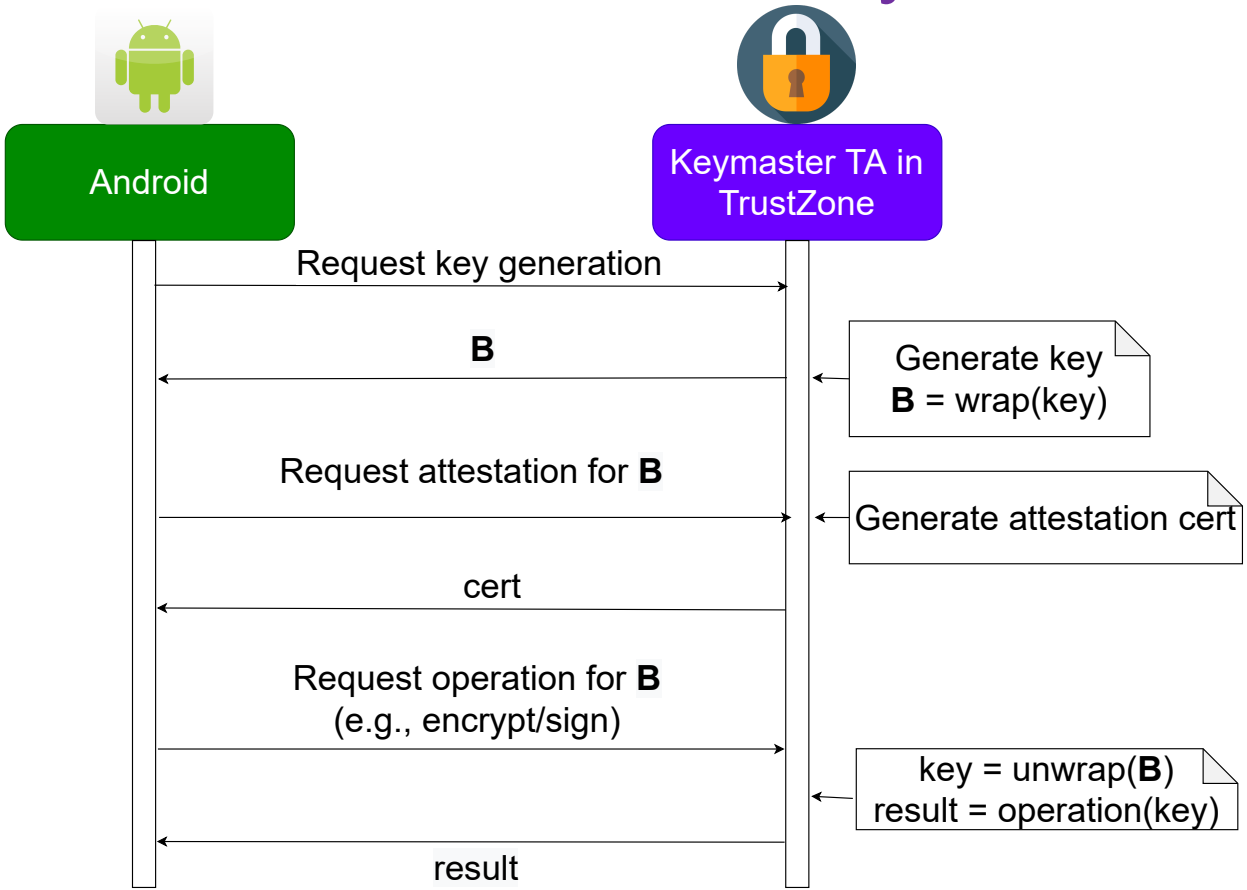

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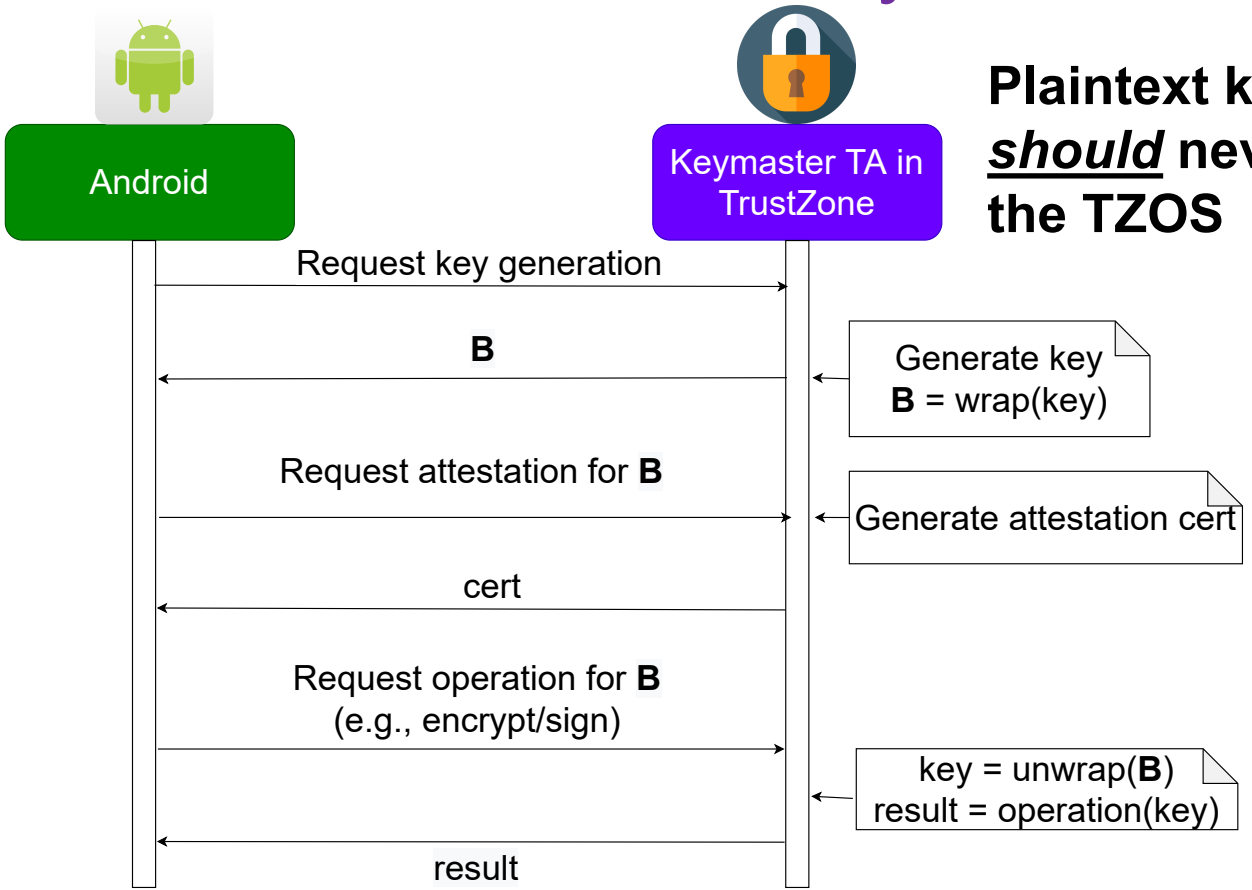


Plaintext key material *should* never leave the TZOS

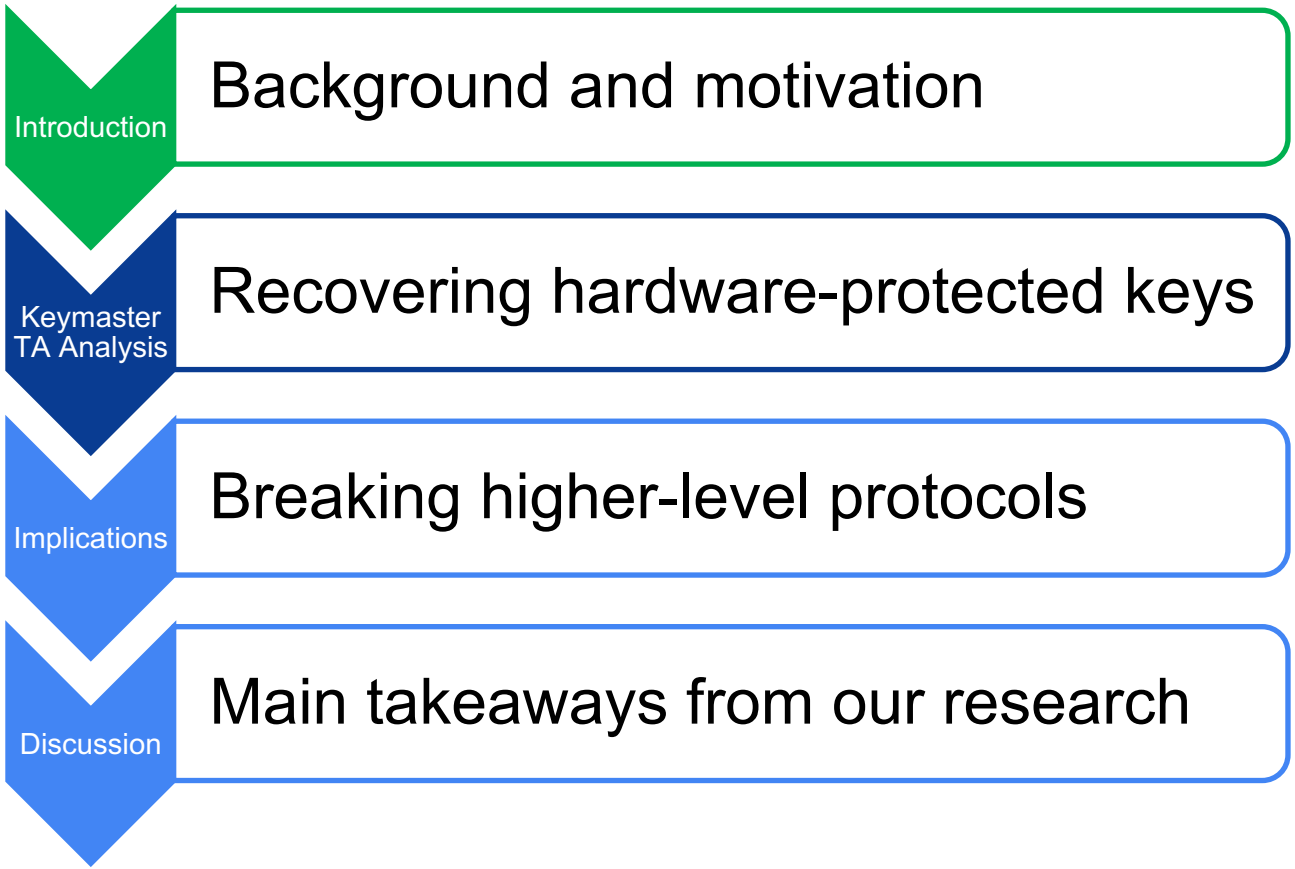
What’s the context?

We need to protect cryptographic keys of applications

Only the Keymaster should access key material

But is it guaranteed?

Agenda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Disclaimer

Where do you start?

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Download the firmware of the specific model

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Read public documentation and security certifications

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Reverse-engineer using Ghidra

Repeat for 26 firmwares

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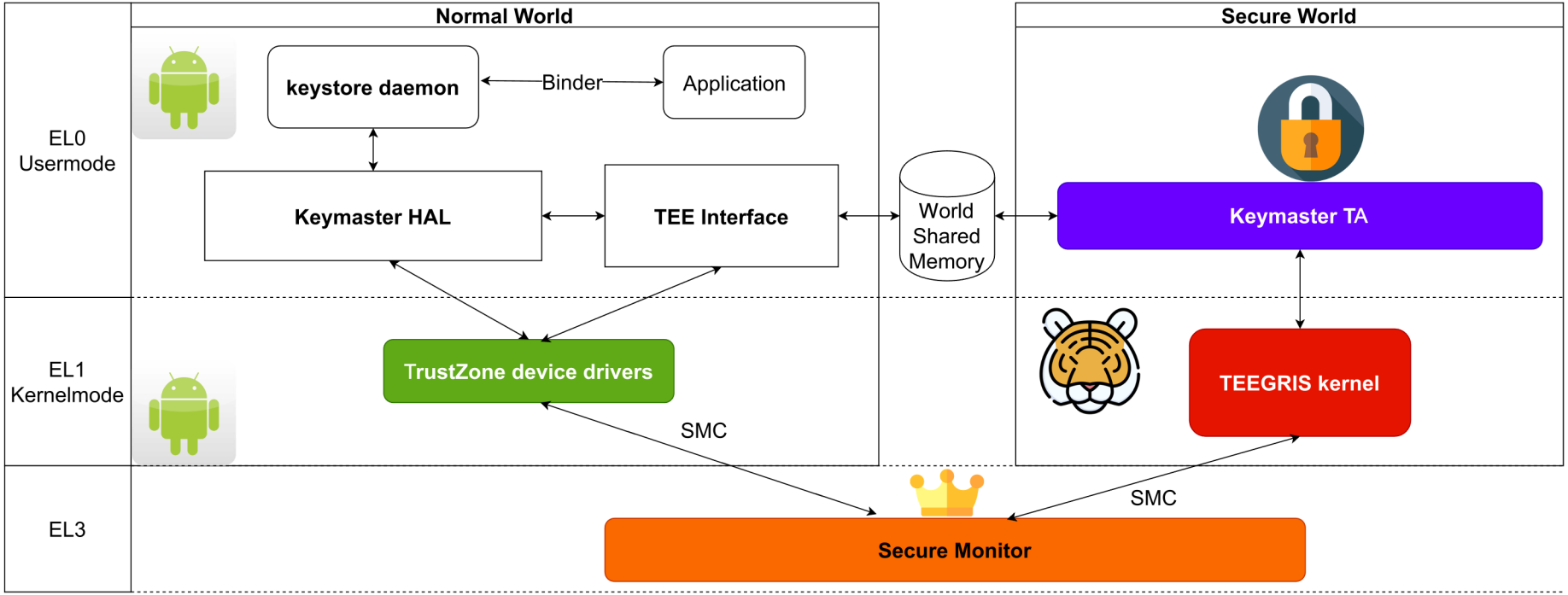
How to interact with the Keymaster?



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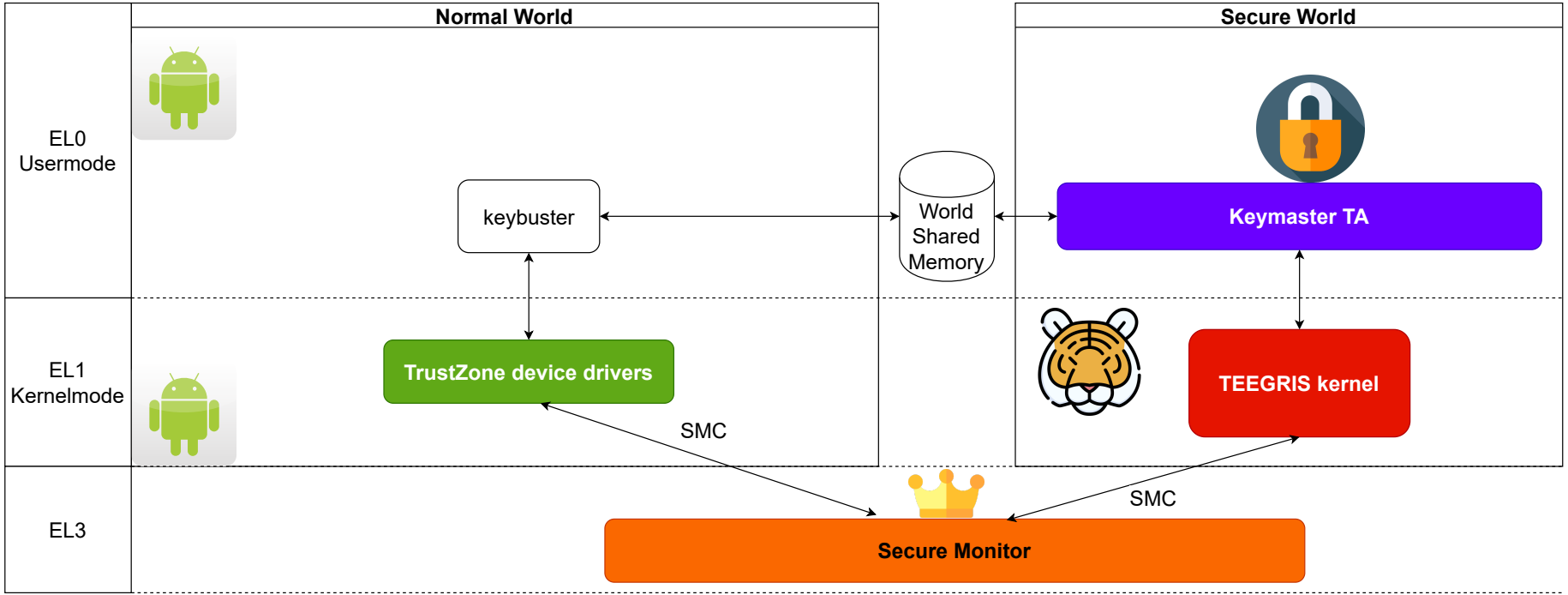
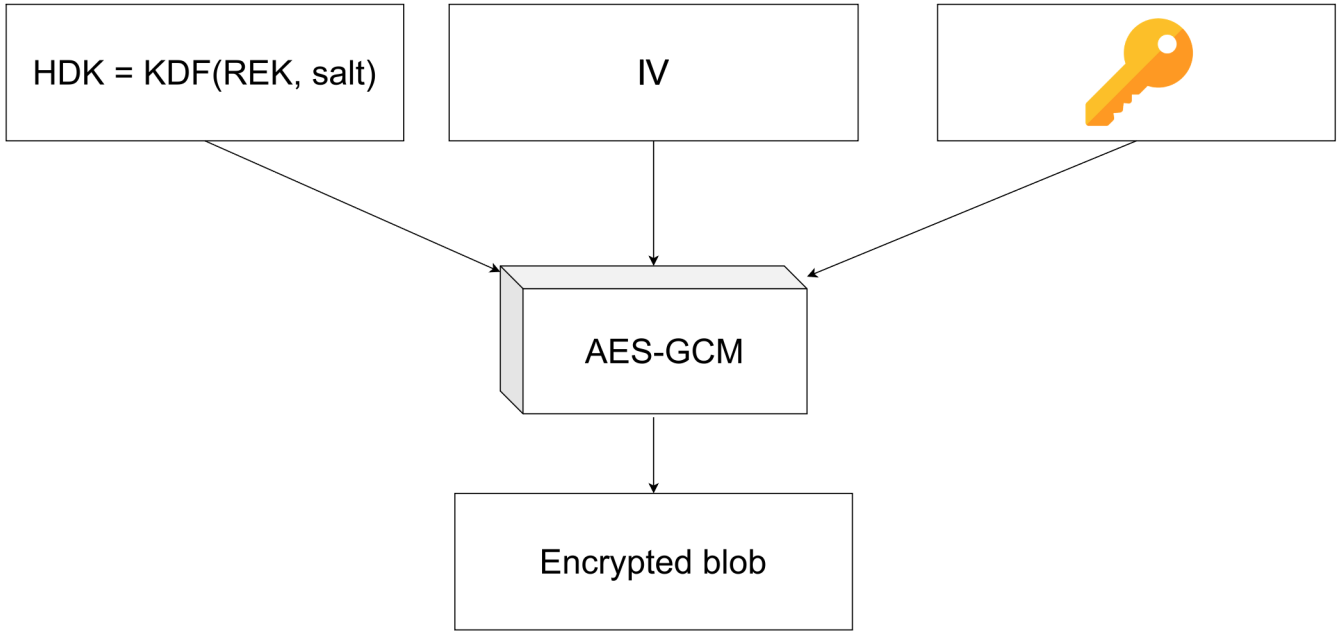
Keybuster: tool to interact with the Keymaster



Key Blob Encryption

The Keymaster TA encrypts key material inside blobs.



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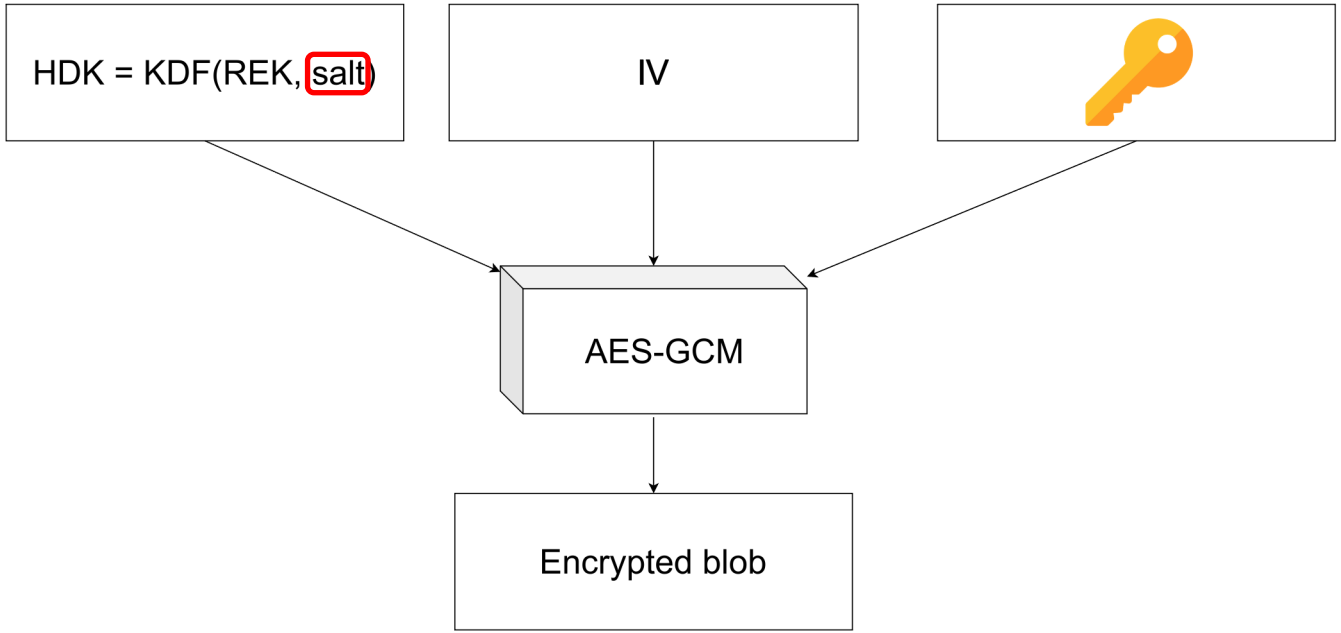

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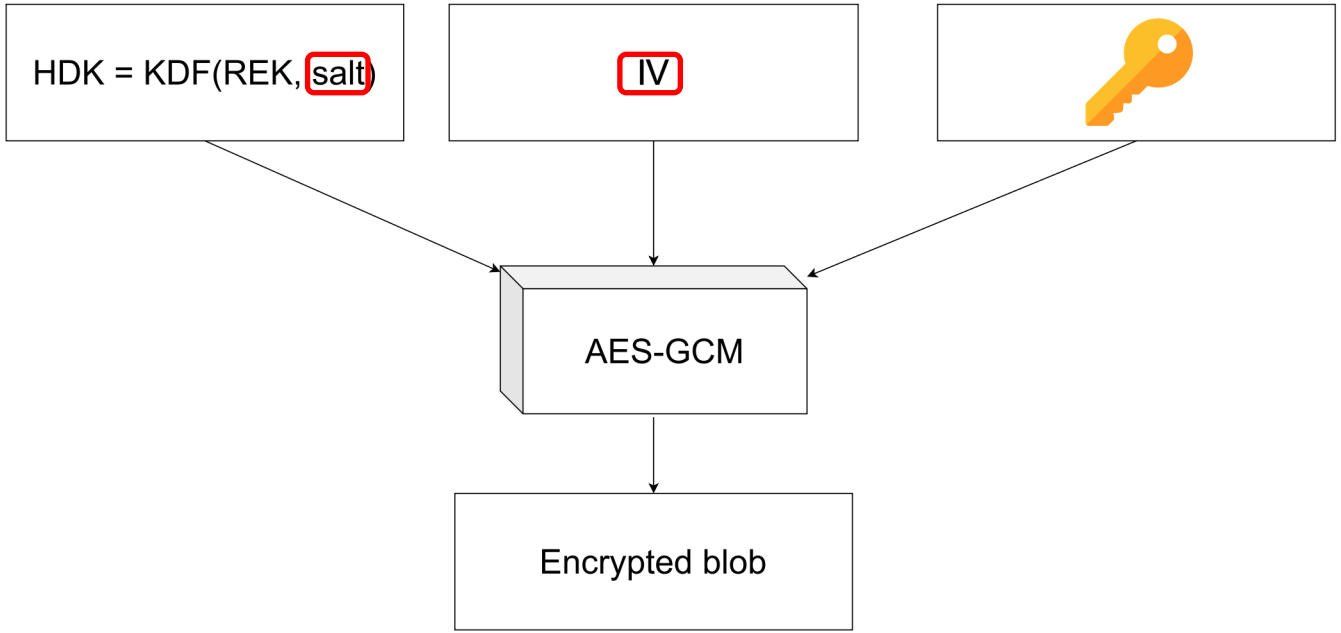

KDF versions of key blobs

salt = SHA-256(salt_seq)

Where salt_seq is one of the following sequences:

v15 blob
"MDFPP HW Keymaster HEK v15\x00"
"ID"
"\x02\x00\x00\x00"
"id"
"DATA"
"\x04\x00\x00\x00"
"data"

v20-s9 blob
"MDFPP HW Keymaster HEK v20\x00"
root_of_trust
"ID"
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v20-s10 blob
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MDFPP can explain the variations

SAMSUNG

Common Criteria and FIPS-validated devices for the security conscious.

Common Criteria-Certified Devices, MDFPP v3

Supported on Android 10

- Samsung Galaxy Note20 5G | Note20 Ultra 5G
- Samsung Galaxy Tab S7 | Tab S7+
- Samsung Galaxy S20 FE 5G
- Samsung Galaxy S20 5G | S20+ 5G | S20 Ultra 5G
- Samsung Galaxy S20 Tactical Edition
- Samsung Galaxy Z Flip | Z Flip 5G
- Samsung Galaxy XCover Pro
- Samsung Galaxy XCover FieldPro
- Samsung Galaxy A71 5G
- Samsung Galaxy A51 I A51 5G
- Samsung Galaxy S10e | S10 | S10+ | S10 5G
- Samsung Galaxy Note10 | Note10+ | Note10+ 5G
- Samsung Galaxy Fold | Fold 5G
- Samsung Galaxy Z Fold2
- Samsung Galaxy S9 | S9+
- Samsung Galaxy Note9
- Samsung Galaxy Tab S6 | Tab S6 5G
- Samsung Galaxy Tab Active3
- Samsung Galaxy Tab S4

IV Reuse Attack (v15/v20-s9)

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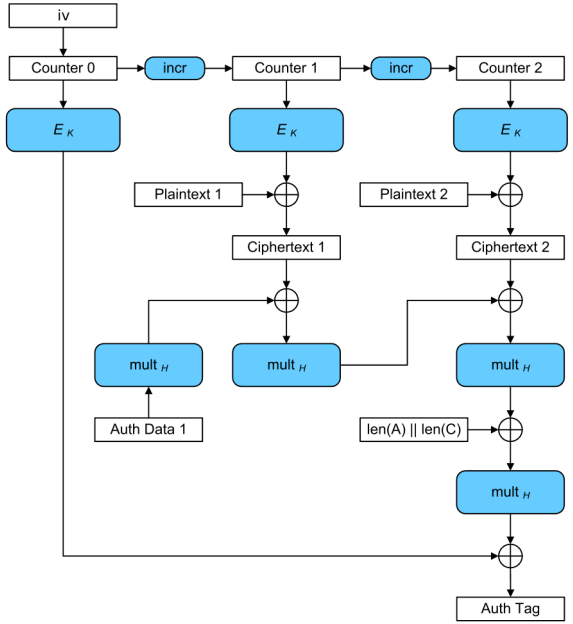

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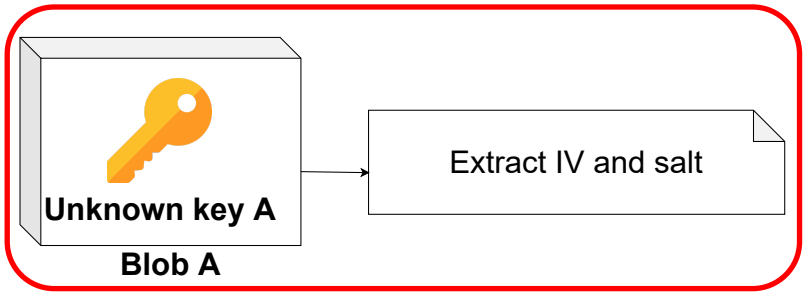

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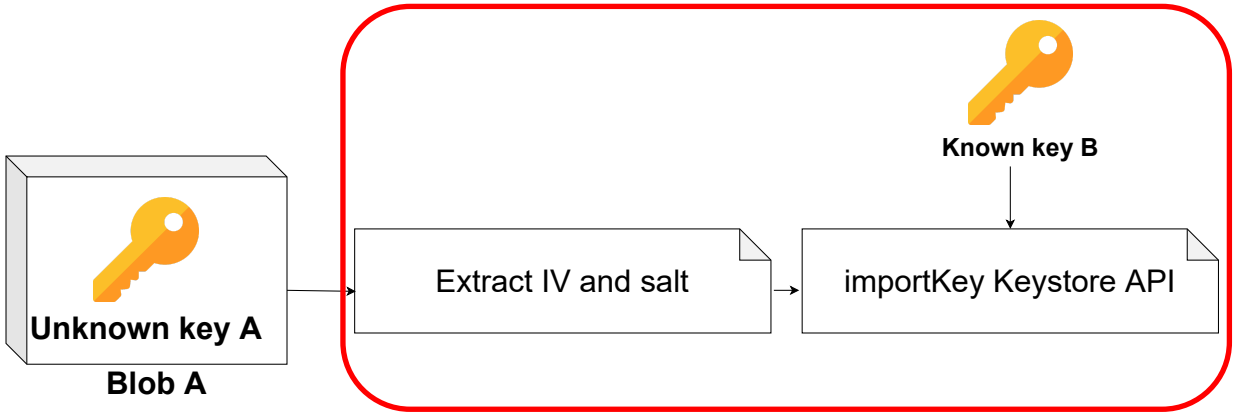

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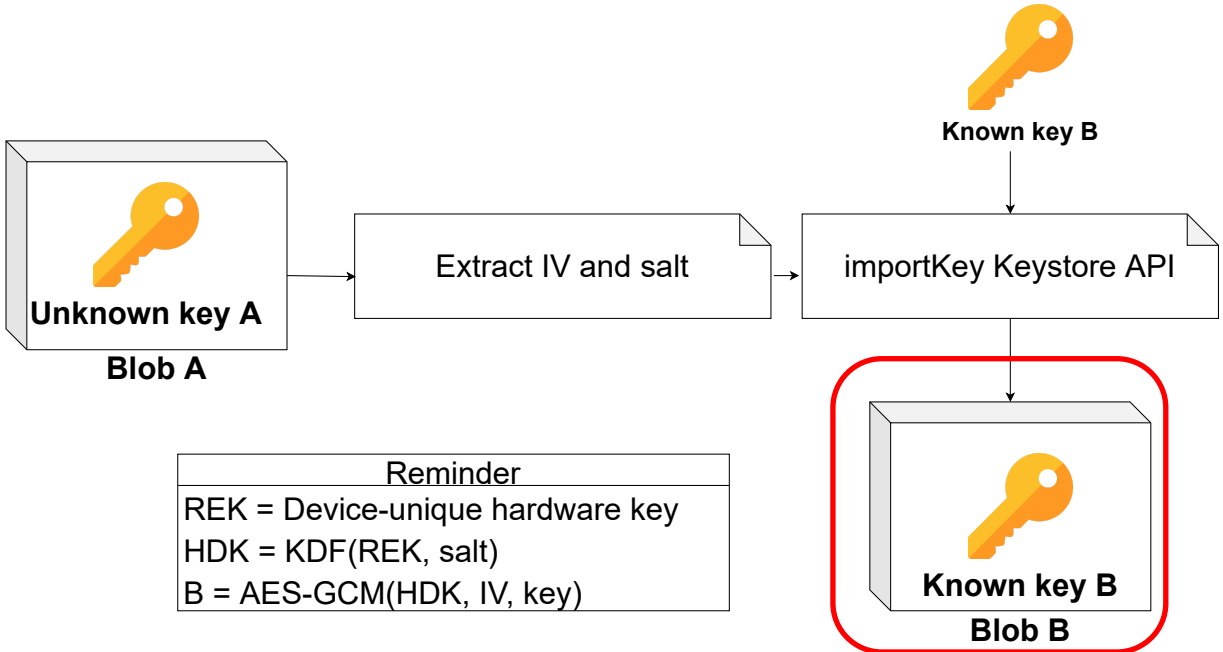

Reminder
REK = Device-unique hardware key
HDK = KDF(REK, salt)
B = AES-GCM(HDK, IV, key)

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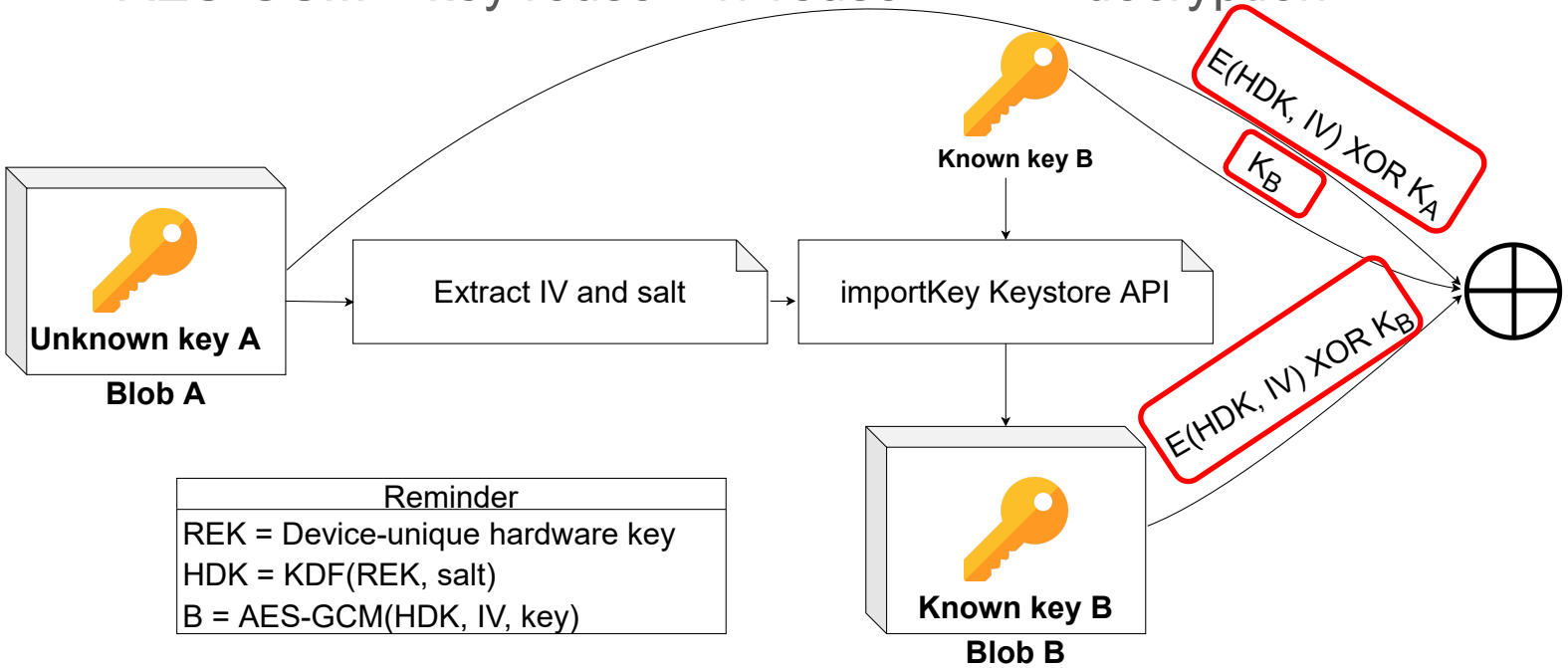

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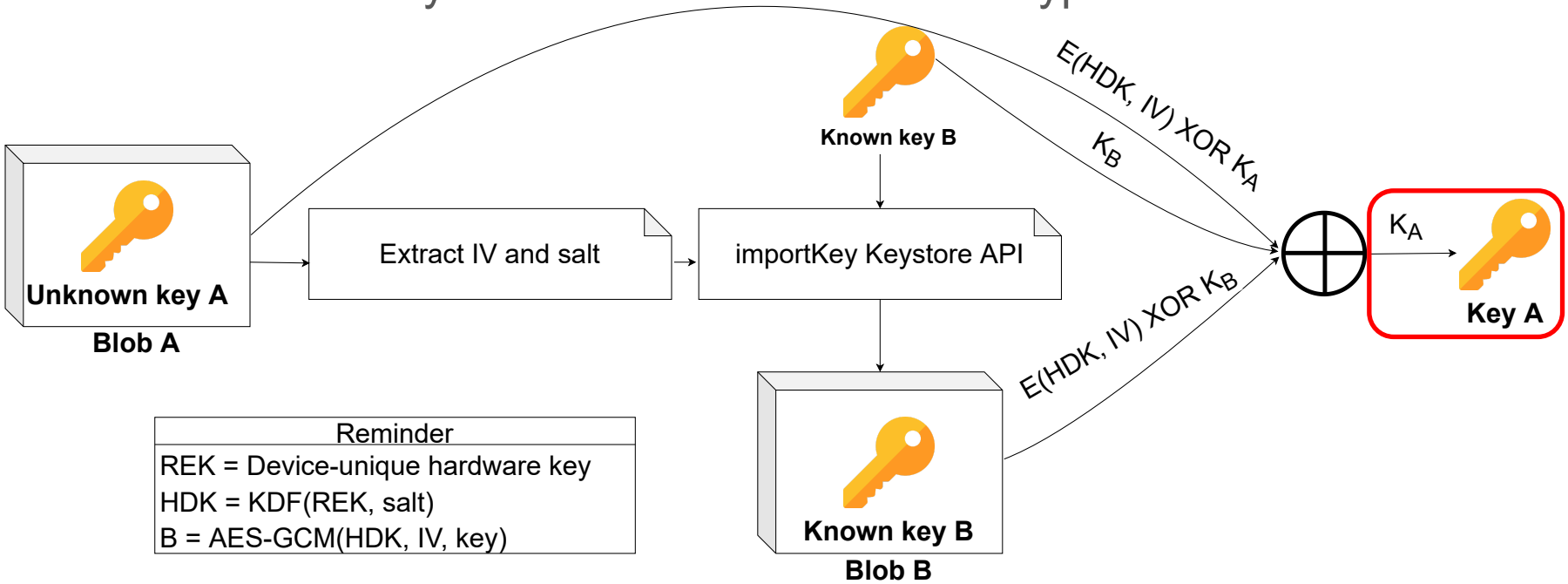
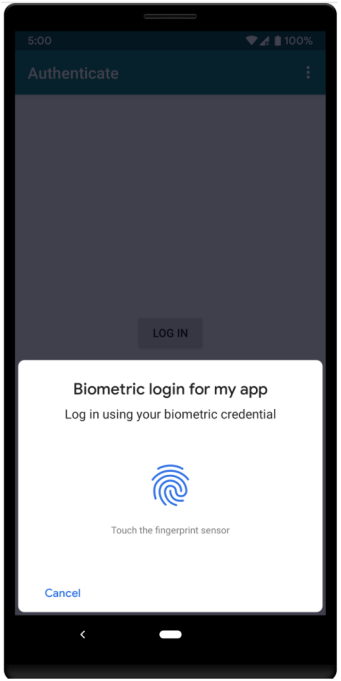
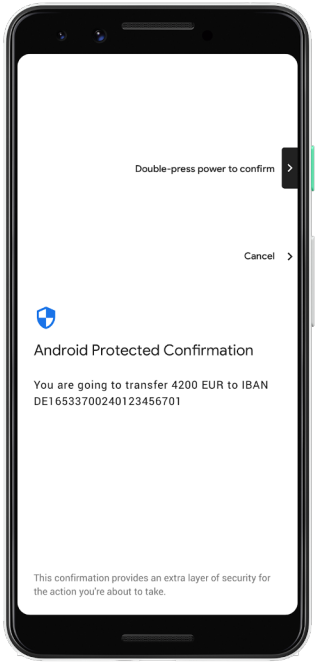


Bypassing Authentication and Confirmation

We can bypass any key usage restriction without user presence/consent





Images from Android Developers Blog

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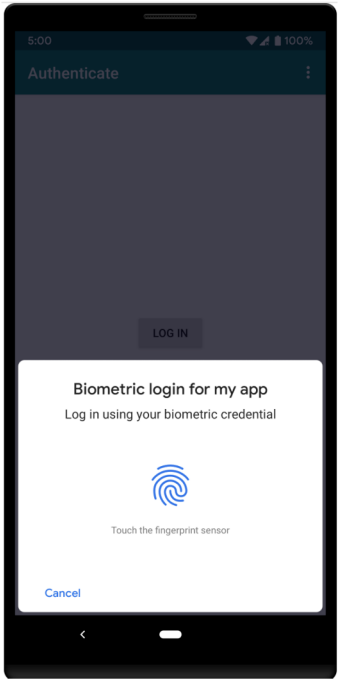

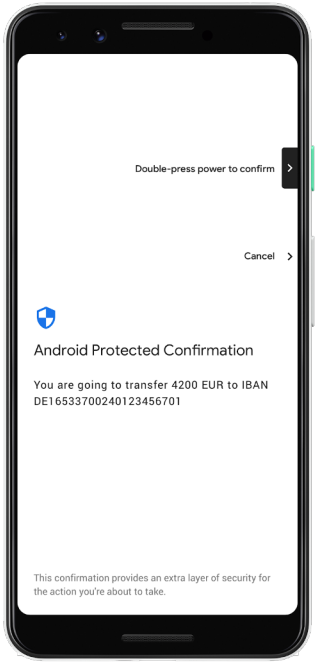

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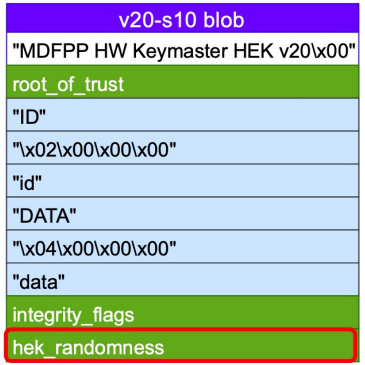
Downgrade Attack

- V20-s10 has randomized salt –> no trivial key reuse



Downgrade Attack

- V20-s10 has randomized salt –> no trivial key reuse
- **Latent code** allows creation of v15 blobs

v20-s10 blob
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root_of_trust
"ID"
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"data"
integrity_flags
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Downgrade Attack

- V20-s10 has randomized salt –> no trivial key reuse
- **Latent code** allows creation of v15 blobs
- A privileged attacker can exploit this to force all new blobs to version v15

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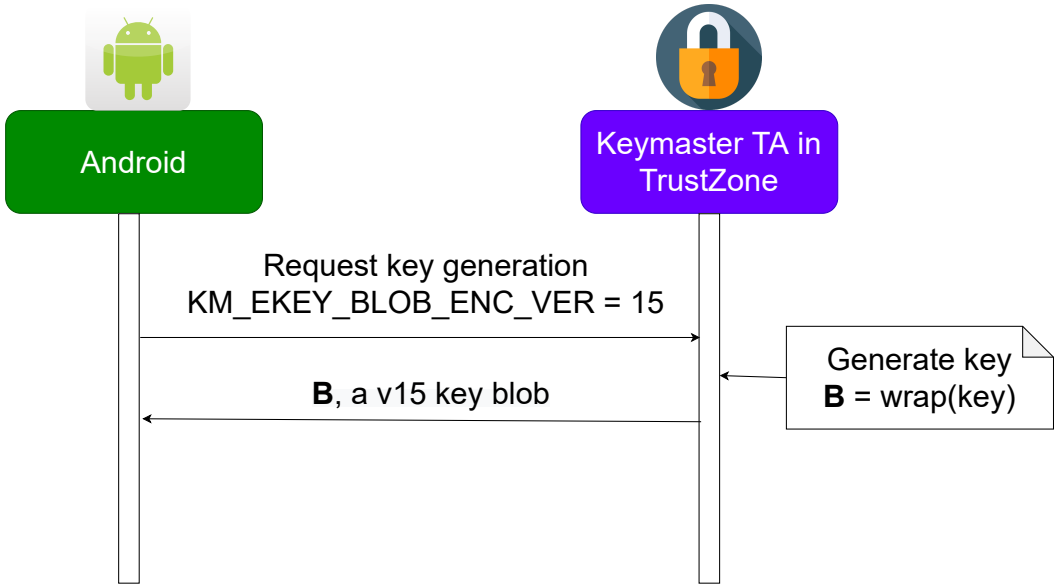

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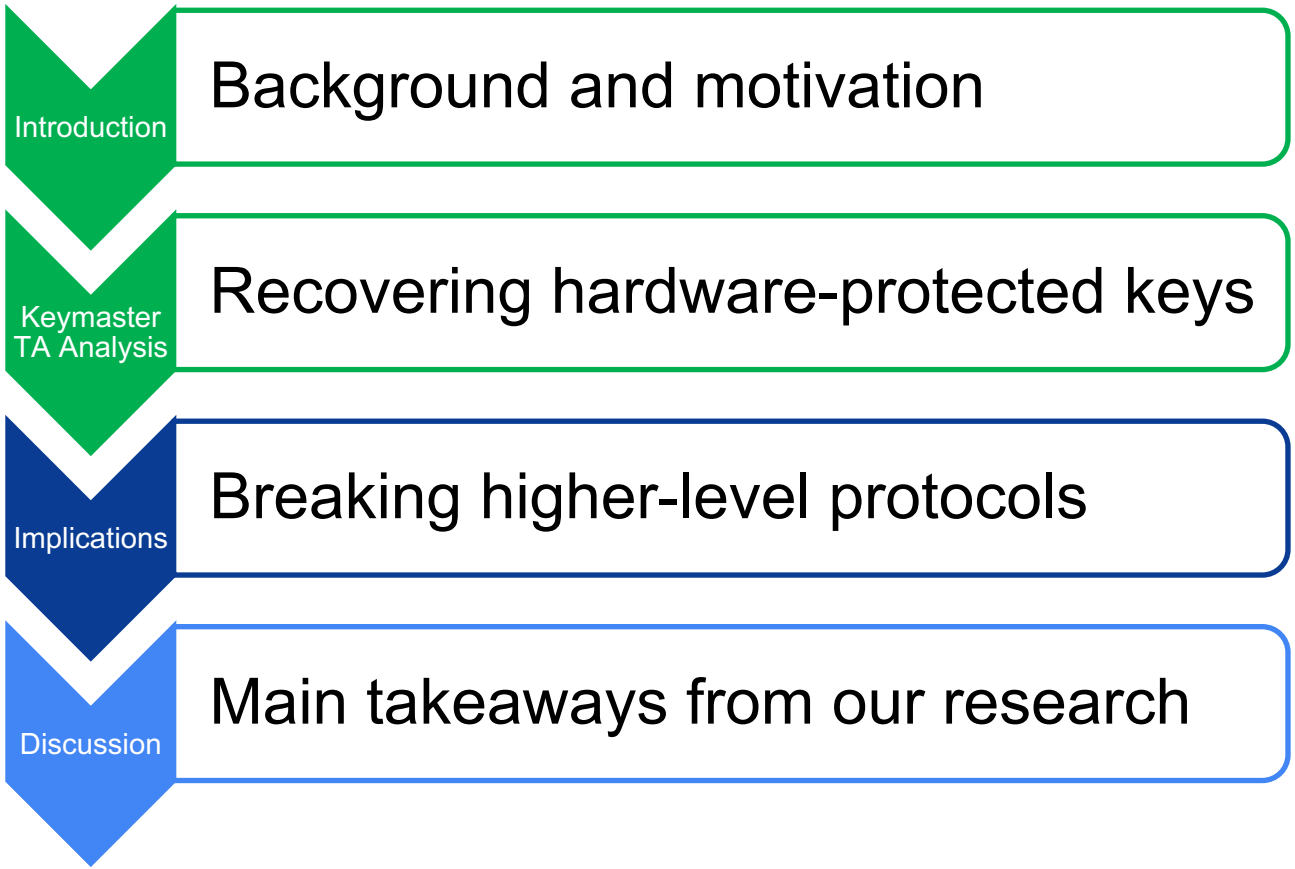
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FIDO2 WebAuthn

Allows passwordless authentication

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Authentication keys live inside a “platform authenticator”

FIDO2 WebAuthn

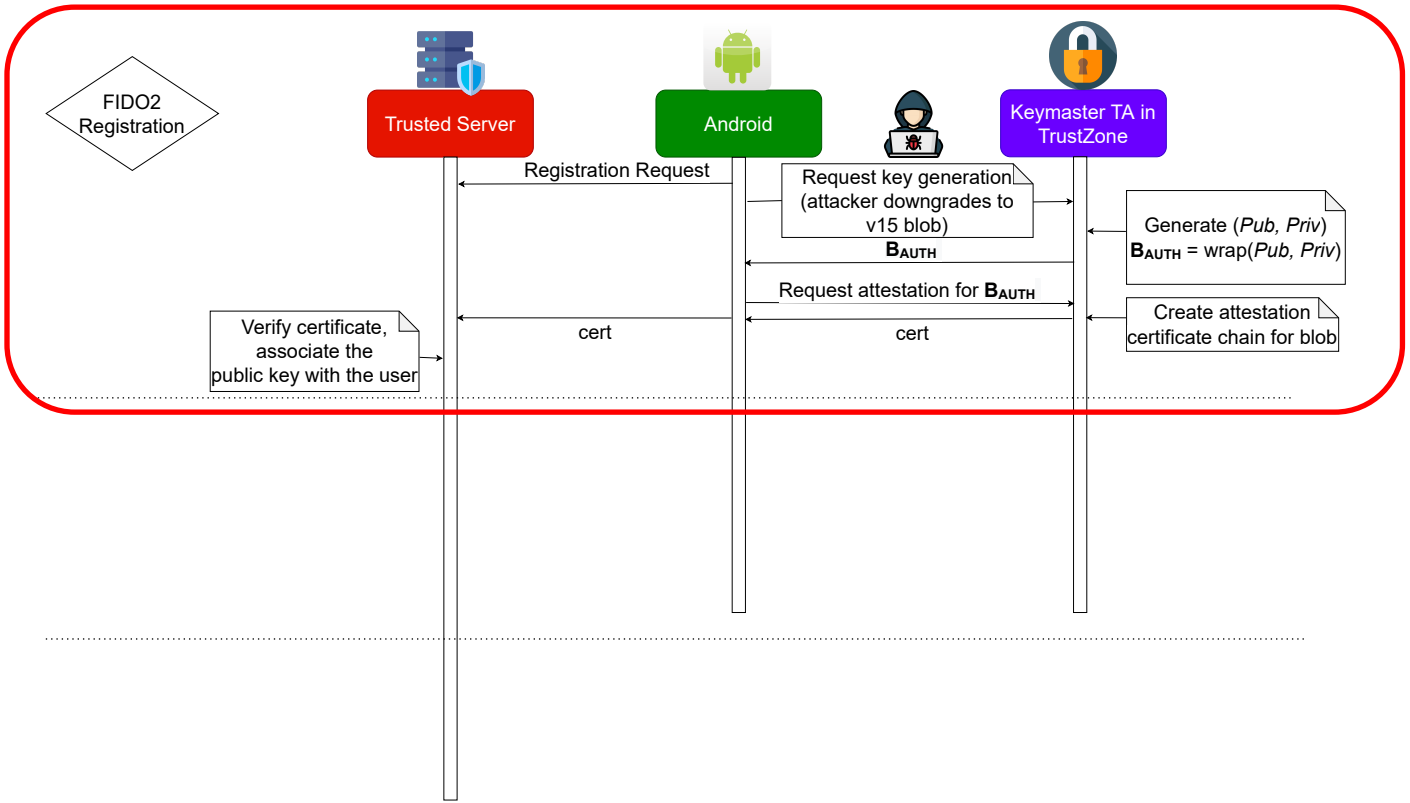
Allows passwordless authentication

Authentication keys live inside a “platform authenticator”

Hard to extract the keys from the secure element

Or to clone the platform authenticator

Bypassing FIDO2 WebAuthn



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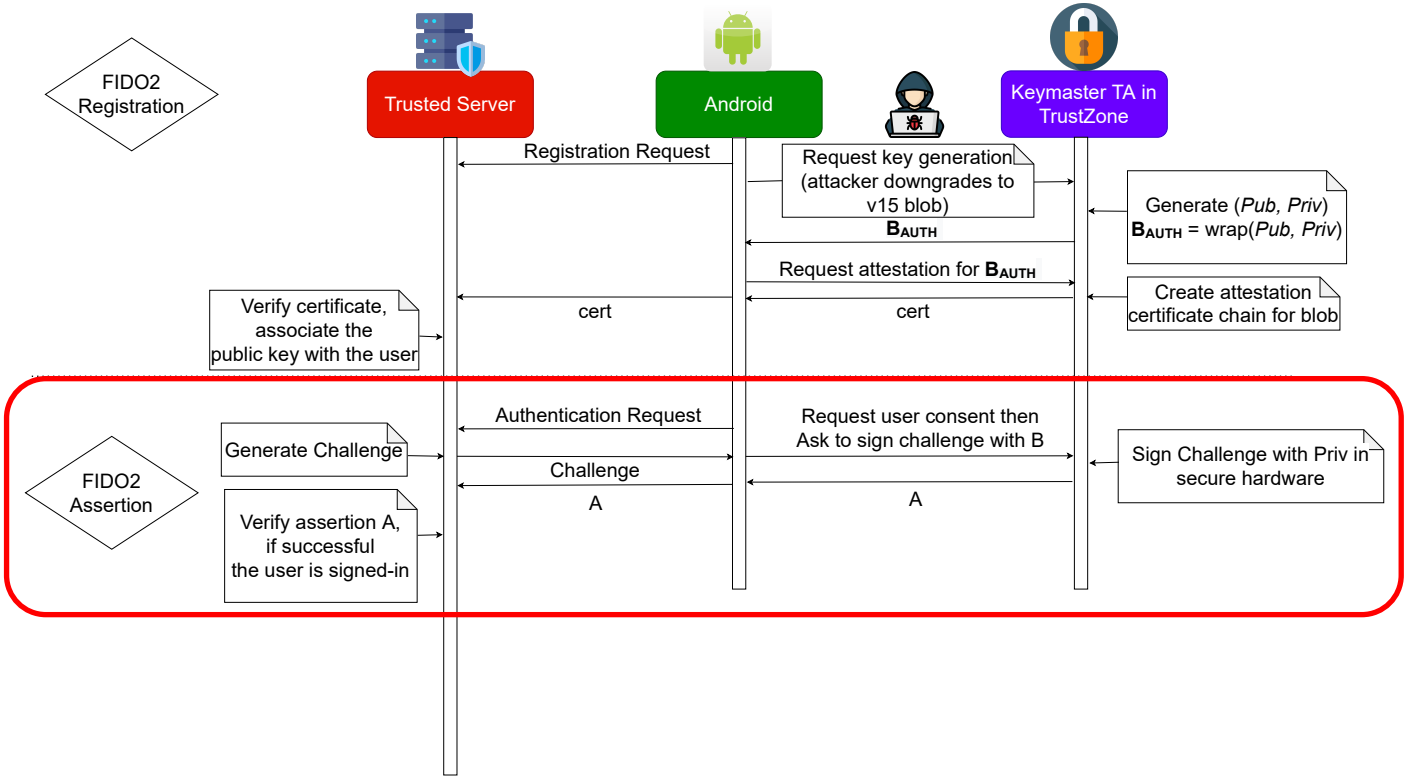

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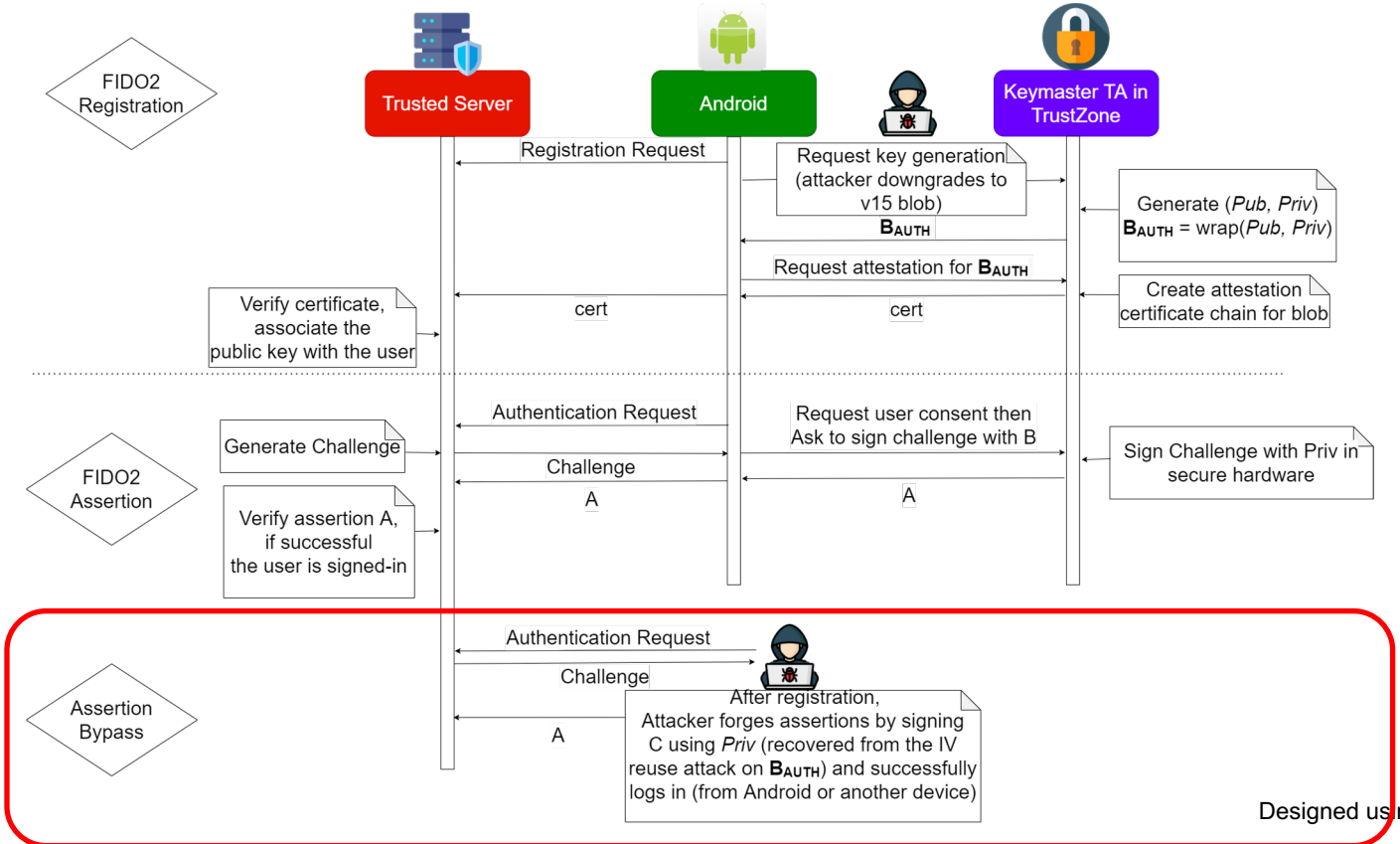

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Bypassing FIDO2 WebAuthn Demo #1

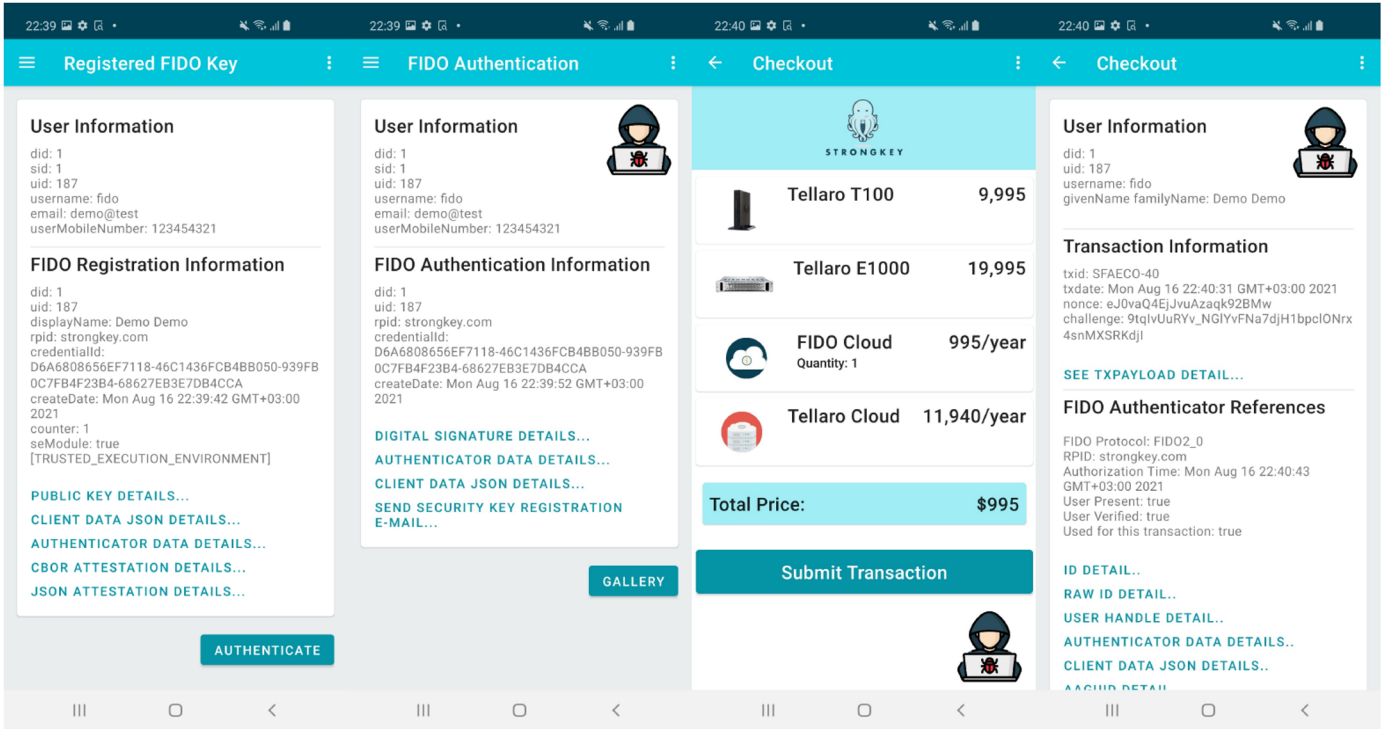
```
beyond1:/data/local/tmp # ./gdbserver --attach :1337 $(pidof android.hardware.keymaster@4.0-service)
Attached; pid = 5190
Listening on port 1337
```

(a) Attaching a GDB debugger to the Keymaster HAL process

```
Breakpoint 2, 0x00000077dae6e514 in nwd_generate_key () from target:/vendor/lib64/libkeymaster_helper_vendor.so
intercepted request to nwd_generate_key
copy old key parameters to new buffer
$1 = 0x7759c24000
$2 = 0x7759c24000
add new parameter (KM_EKEY_BLOB_ENC_VER, 15)
switch to new parameters - this forces the generation of a v15 blob
Breakpoint 4, 0x00000077dae6e544 in nwd_generate_key () from target:/vendor/lib64/libkeymaster_helper_vendor.so
dump the key blob that the keymaster returned
start 0x7759c3b280, end 0x7759c3b4d2, len 252
dumped to result.bin
```

(b) During registration, the GDB script performs the downgrade attack

Bypassing FIDO2 WebAuthn Demo #2



(c) Registration success (d) Authentication success (e) Checkout example (f) Re-authentication success

What did we find?

Attackers could steal cryptographic keys of applications

Attackers could steal your identity

Responsible Disclosure #1

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  - S9, J3 Top, J7 Top, J7 Duo, TabS4, Tab-A-S-Lite, A6 Plus, A9S
  - CVE-2021-25444 with High severity
  - Removed the option to add a custom IV from the API

SVE-2021-21948 (CVE-2021-25444): IV reuse in Keymaster TA

Severity: High
Affected versions: O(8.1), P(9.0), Q(10.0)
Reported on: May 25, 2021
Disclosure status: Privately disclosed.
An IV reuse vulnerability in keymaster prior to SMR AUG-2021 Release 1 allows decryption of custom keyblob with privileged process.
The patch prevents reusing IV by blocking addition of custom IV.

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Responsible Disclosure #2

- Jun ‘21: Samsung rejected the downgrade attack
  - “There is no application created with the key blob version as v15. And any of the applications cannot change its key blob version for it to be exploitable.”

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- Aug ‘21: Samsung rated the downgrade attack as “very Low severity”
  - “we think that there is no practical security impact on this”

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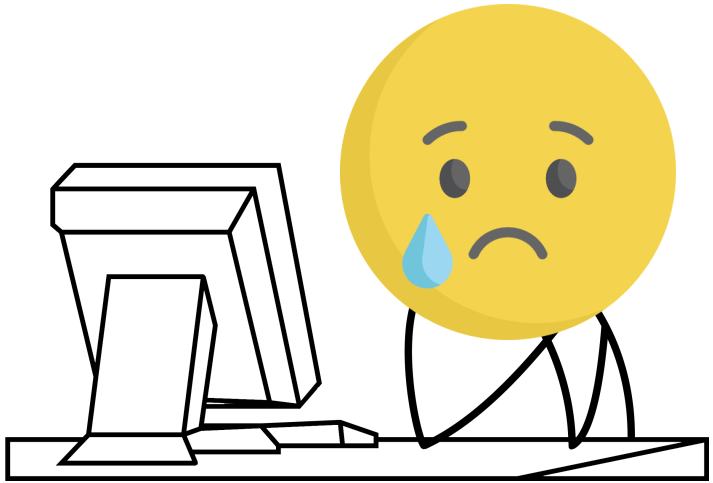
  - “we think that there is no practical security impact on this”



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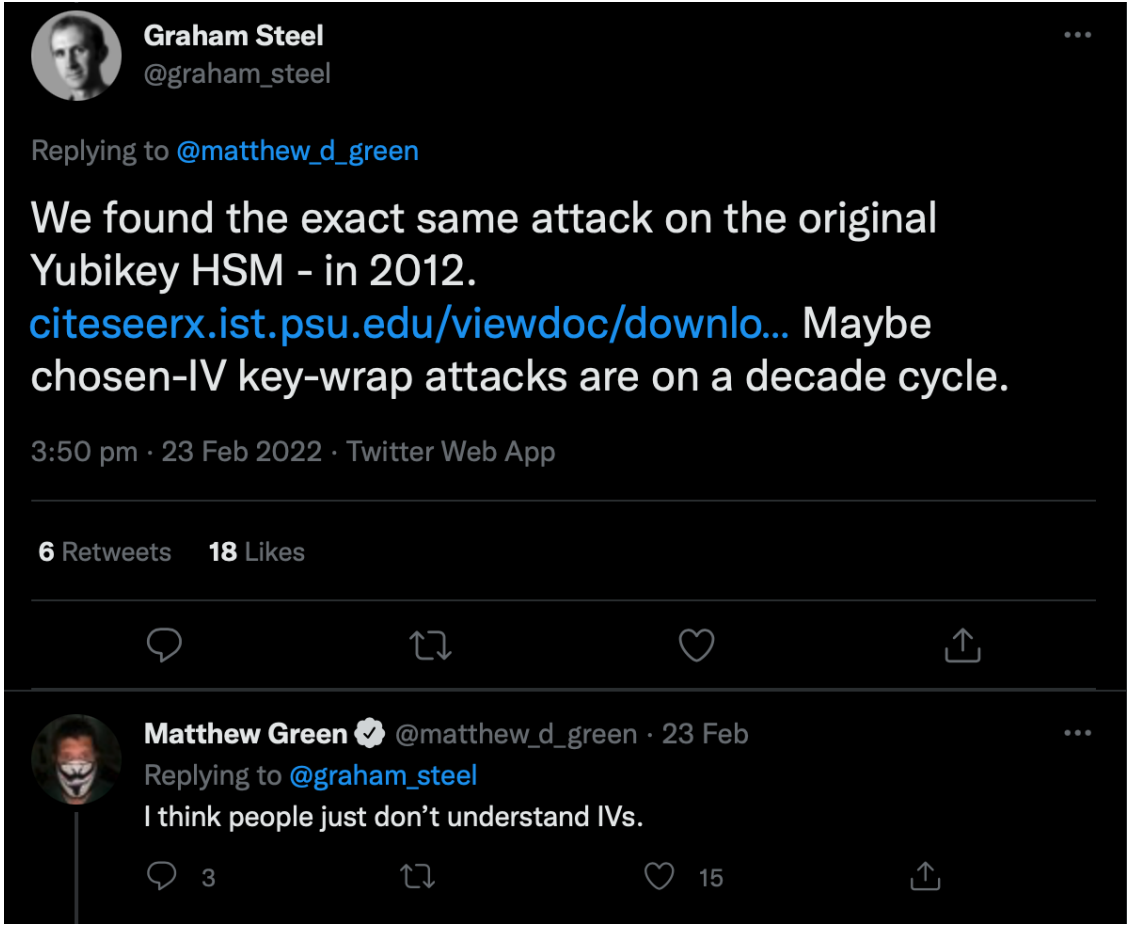
- Oct ‘21: Samsung patched Android P or later, including S10/S20/S21
  - CVE-2021-25490 with High severity
  - Released a patch that completely removes the legacy key blob implementation

SVE-2021-22658 (CVE-2021-25490): Downgrade attack in Keymaster TA

Severity: High
Affected versions: P(9.0), Q(10.0), R(11.0)
Reported on: July 16, 2021
Disclosure status: Privately disclosed.
A keyblob downgrade attack in keymaster prior to SMR Oct-2021 Release 1 allows attacker to trigger IV reuse vulnerability with privileged process.
The patch removes the legacy implementation for minor keyblob.

No Security By Obscurity

Return of the IV Reuse Attack



Graham Steel
@graham_steel

Replying to @matthew_d_green

We found the exact same attack on the original Yubikey HSM - in 2012. citeseerx.ist.psu.edu/viewdoc/downlo... Maybe chosen-IV key-wrap attacks are on a decade cycle.

3:50 pm · 23 Feb 2022 · Twitter Web App

6 Retweets **18** Likes

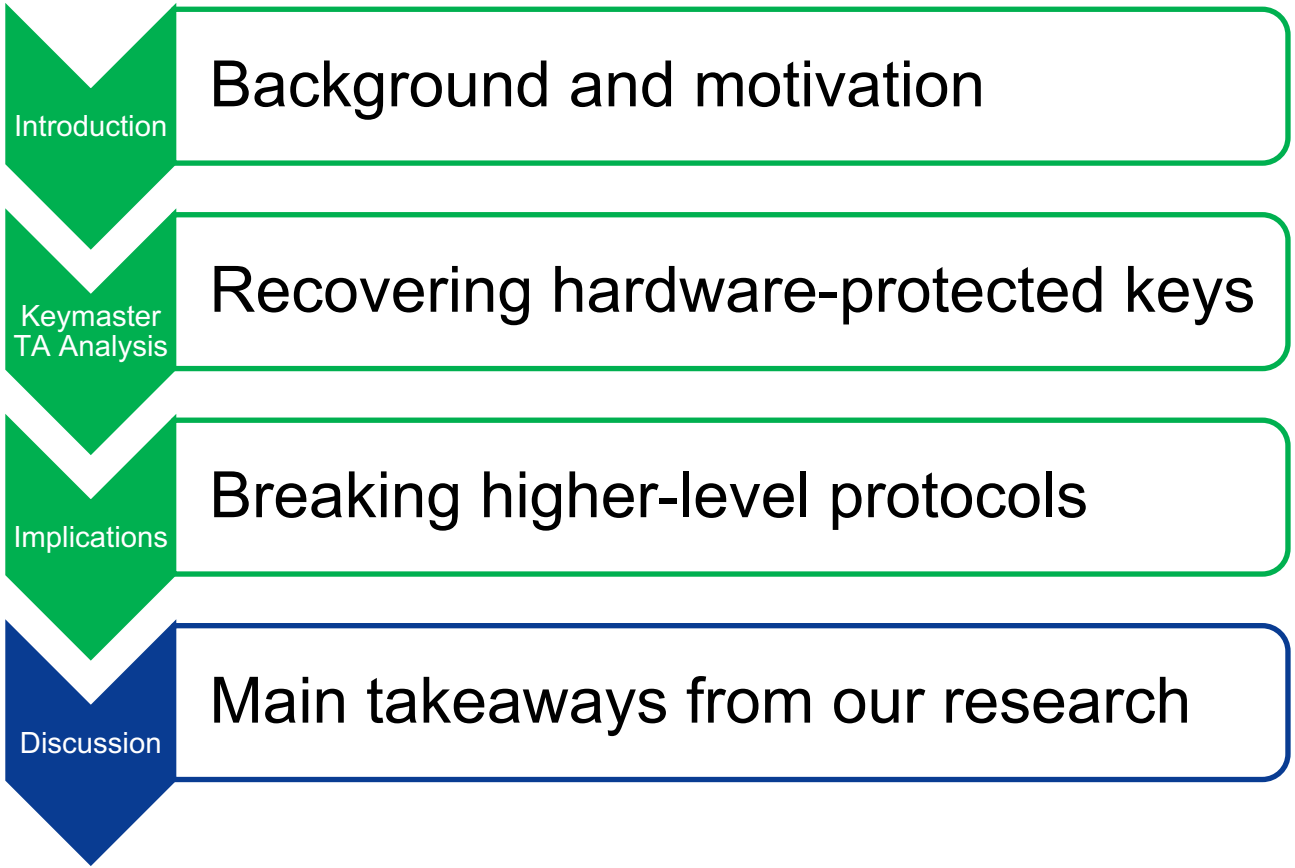
Matthew Green @matthew_d_green · 23 Feb

Replying to @graham_steel

I think people just don't understand IVs.

3 15

Agenda


Introduction
Background and motivation
Keymaster TA Analysis
Recovering hardware-protected keys
Implications
Breaking higher-level protocols
Discussion
Main takeaways from our research

Low-Level Cryptographic Issues

- ❌ Allowing client to set IV
- ❌ Allowing client to set encryption version
- ❌ Latent code in security-critical application
- ❌ Encryption version persists across “upgrades”

Low-Level Cryptographic Issues

❌ Allowing client to set IV
❌ Allowing client to set encryption version
❌ Latent code in security-critical application
❌ Encryption version persists across “upgrades”

✅ Use a unique IV / misuse resistant AEAD (AES-GCM-SIV) / Tink
✅ Disallow choice of encryption version
✅ Reduce attack surface in security-critical application
✅ Always use the latest encryption version

The Gap in Composability

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- ✅ Include encryption version in attestation certificate
- ✅ Uniform open-standard by Google for the Keymaster HAL and TA

Upgrading Android Attestation: Remote Provisioning

25 March 2022

Posted by Max Bires, Software Engineer

Why Change?

The two primary motivating factors for changing the way we provision attestation certificates to devices are to allow devices to be recovered post-compromise and to tighten up the attestation supply chain. In today's attestation scheme, if a device model is found to be compromised in a way that affects the trust signal of an attestation, or if a key is leaked through some mechanism, the key must be revoked. Due to the increasing number of services that rely on the attestation key signal, this can have a large impact on the consumer whose device is affected.

This change allows us to stop provisioning to devices that are on known-compromised software, and remove the potential for unintentional key leakage. This will go a long way in reducing the potential for service disruption to the user.

Image from Android Developers Blog

Conclusions

Fragmented blackbox designs -> dangerous pitfalls

Open standard design

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Formal analysis by independent researchers

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Open standard design

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Formal analysis by independent researchers

Decades of IV reuse in AES-GCM

Misuse-resistant AEAD / cryptography library

Any questions?

- Extended paper: https://eprint.iacr.org/2022/208.pdf
- Tool + PoC: https://github.com/shakevsky/keybuster

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