Google

Android Security: Taming the Complex Ecosystem

Stanford CS155 guest lecture

2019-05-23

René Mayrhofer, Director of Android Platform Security

Personal Twitter: @rene_mobile

Outline

1. The Ecosystem and State of the Union (*The Marketing Part*)
2. Android Platform Security Model and Implementation (The Systematic Part)
3. Taming Complexity (*The "What I learned" Part*)
4. Where do we go from here (The Future Part)?

State of the (Android) Union

The Android ecosystem in numbers

> 1.300 brands

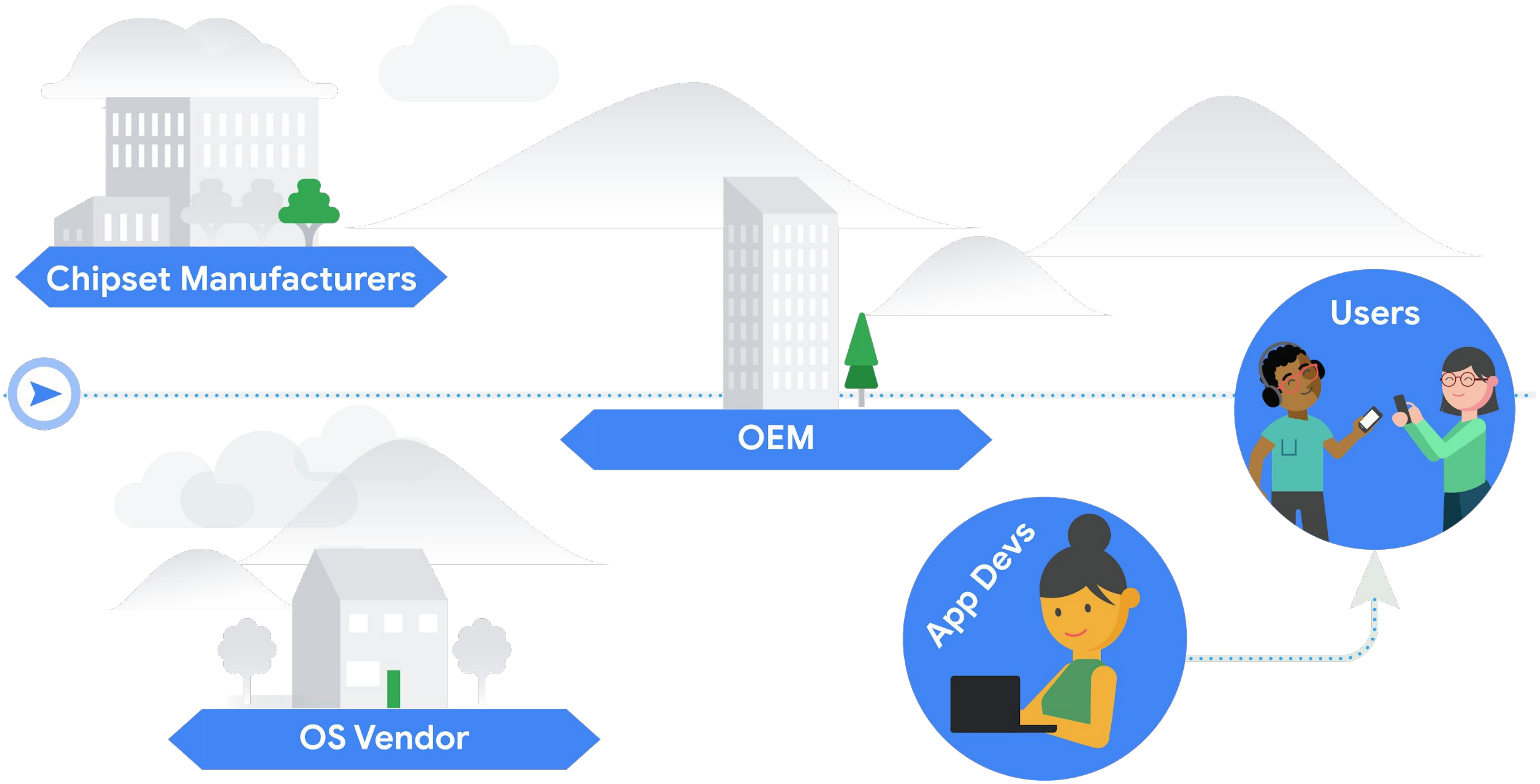
> 24.000 devices

> 1 M apps

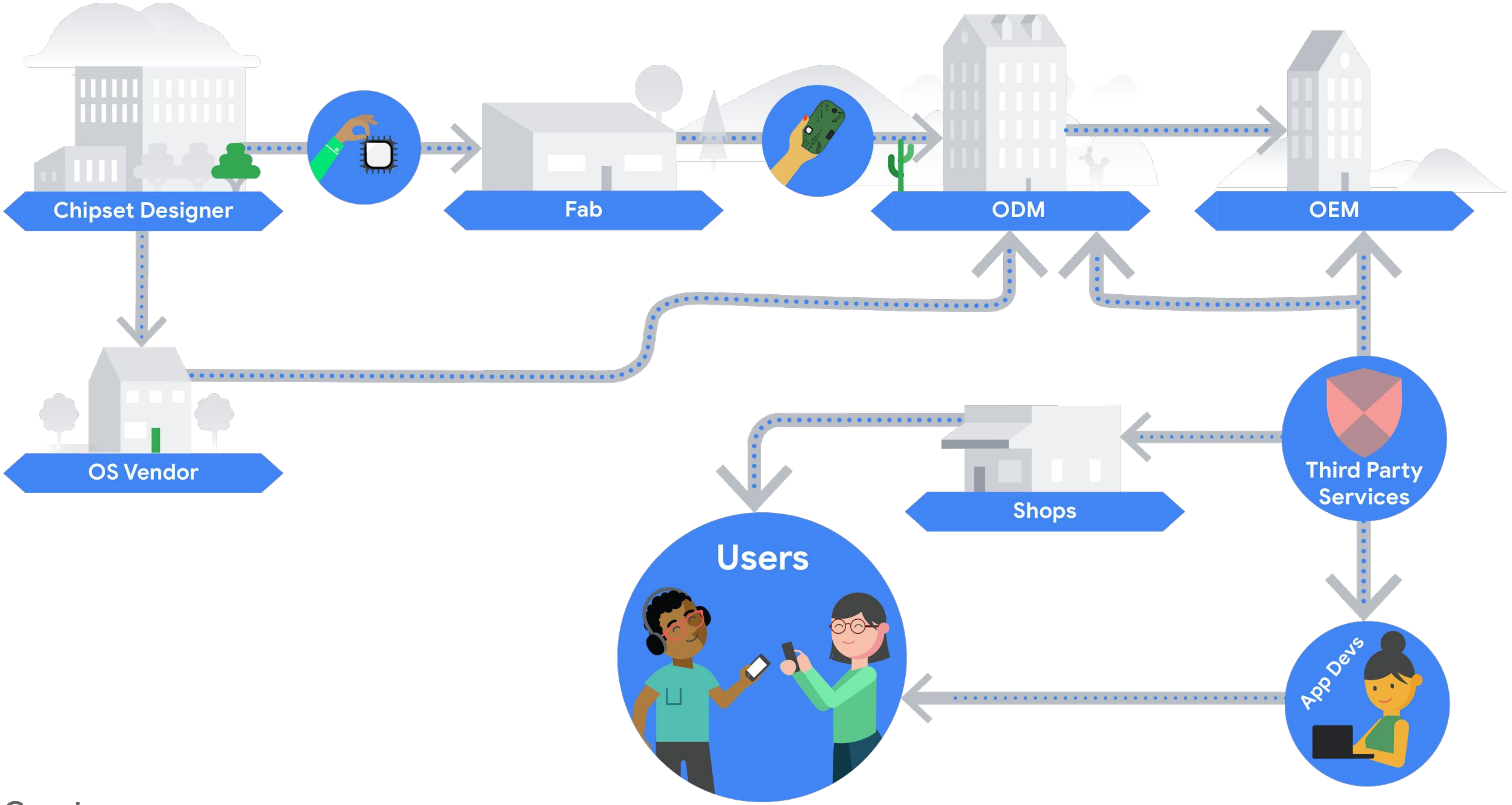
> 2 B users

Google

https://www.blog.google/around-the-globe/google-europe/android-has-created-more-choice-not-less/



Google

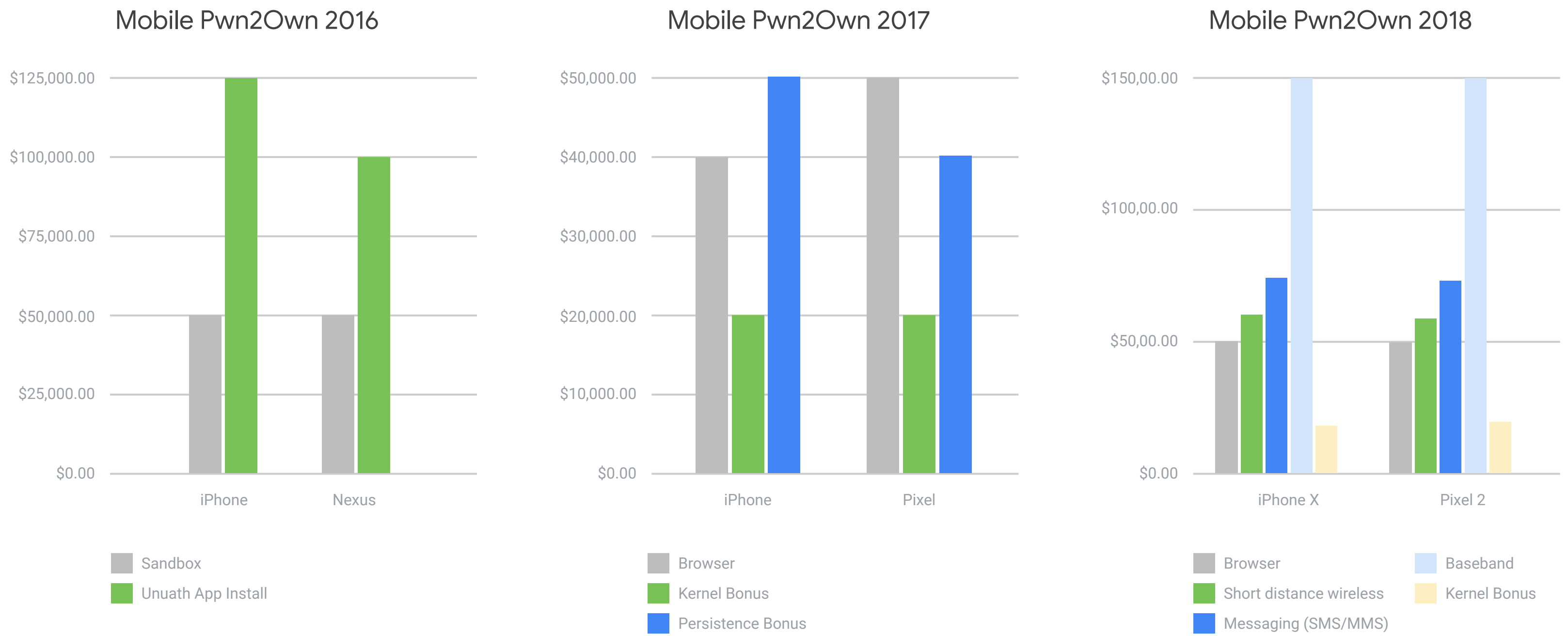

Chipset Designer
Fab
ODM
OEM
OS Vendor
Third Party Services
Shops
Users
App Devs

Google

Measuring exploitation difficulty: 0-day pricing

Google

Measuring exploitation difficulty: 0-day pricing

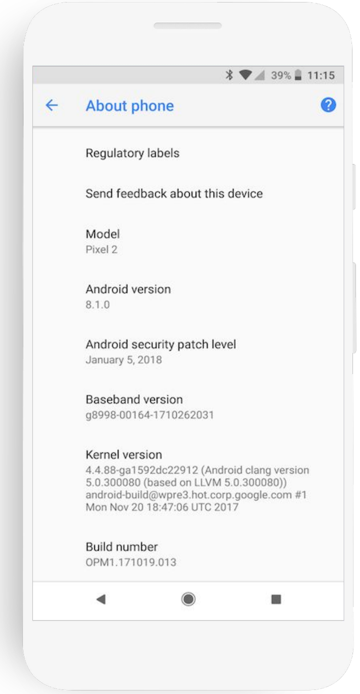


0

critical security vulnerabilities affecting the Android platform in 2018 publicly disclosed without a security update or mitigation available

Google

Android patching has improved



1B

Devices patched in 2018.

29%

more devices patched QoQ in Q4.

84%

more devices patched in Q4 than same time last year.

Malware is a universal risk

Security researchers discover iOS version of Exodus Android spyware

Exodus iOS spyware used against Italian and Turkmenistan users.

By Catalin Cimpanu for Zero Day | April 8, 2019 -- 21:25 GMT (14:25 PDT) | Topic: Security

"This year, we celebrated the 30th anniversary of the World Wide Web. Fast forward thirty years and the threat landscape is exponentially more complex, and the available attack surface is growing faster than it has at any other point in the history of technology," commented Ondrej Vlcek, President of Consumer at Avast.

New research reveals a dozen iPhone apps linked to Golduck malware

08/01/2019 Promon's Security Team

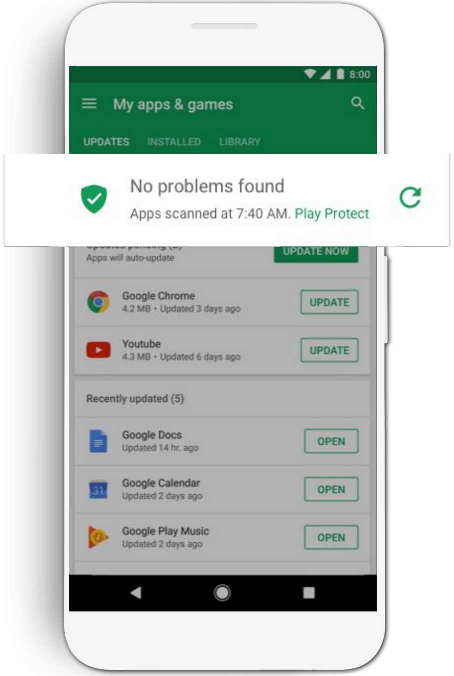
Android Security, App Security, Application Security, Application Shielding, Malware, Mobile App Security

New research from Wandera find over a dozen iPhone apps linked to Golduck malware. The findings underline that fake apps is by no means an Android-only problem.

Google

World's most widely used Anti-Malware solution

Google Play Protect



Security protection for everyone (Play and off-Play).

Always updating to provide the latest protections from **Google AI.**

Scans apps daily - from both within Google Play and outside of it.

Remediates by removing potentially harmful apps (PHA).

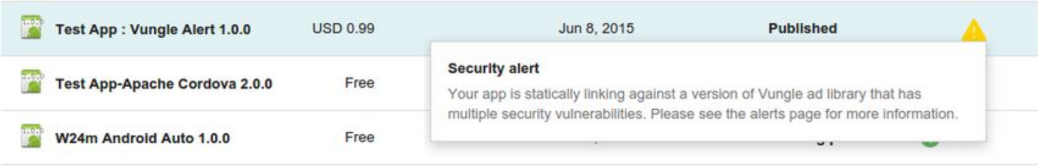
50B
Apps verified per day

2+B
Devices protected

500K
Apps analyzed per day

Play App Security Improvement Program

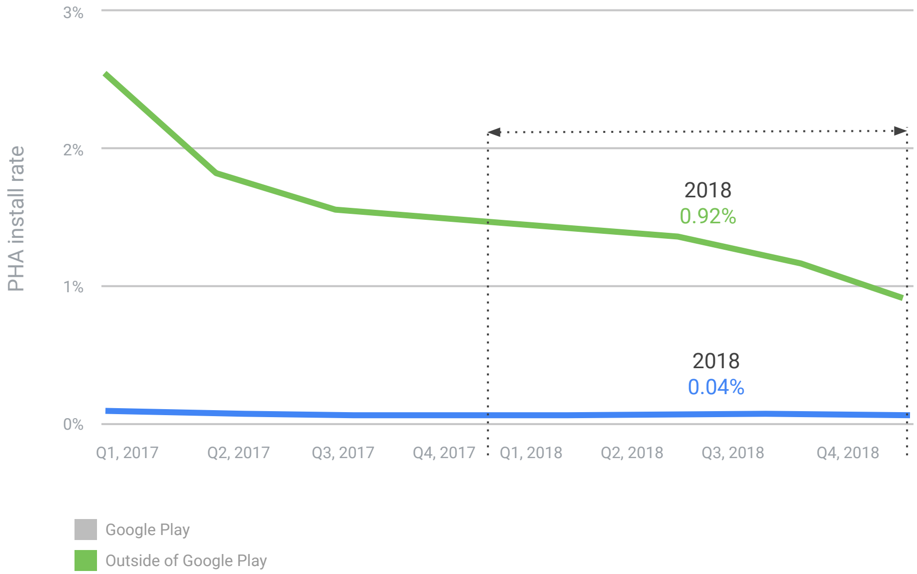
Identifies potential security enhancements when apps are uploaded to Play **300,000** developers have fixed **1,000,000+** Play apps.



Google

Android PHA install rates over time

In 2018, downloading a PHA from Google Play was **0.04%**, and outside of Google Play was **0.92%**.



Google

The Android Platform Security Model

Google

[R. Mayrhofer, J. Vander Stoep, C. Brubaker, N. Kralevich. "*The Android Platform Security Model*', arXiv:1904.05572, April 2019, https://arxiv.org/abs/1904.05572]

Security Goals

1. Protecting user data
    a. Usual: device encryption, user authentication, memory/process isolation
    b. Upcoming: personalized ML on device
2. Protecting device integrity
    a. Usual: malicious modification of devices
    b. Interesting question: against whom?
3. Protecting developer data
    a. Content
    b. IP

Threat Model

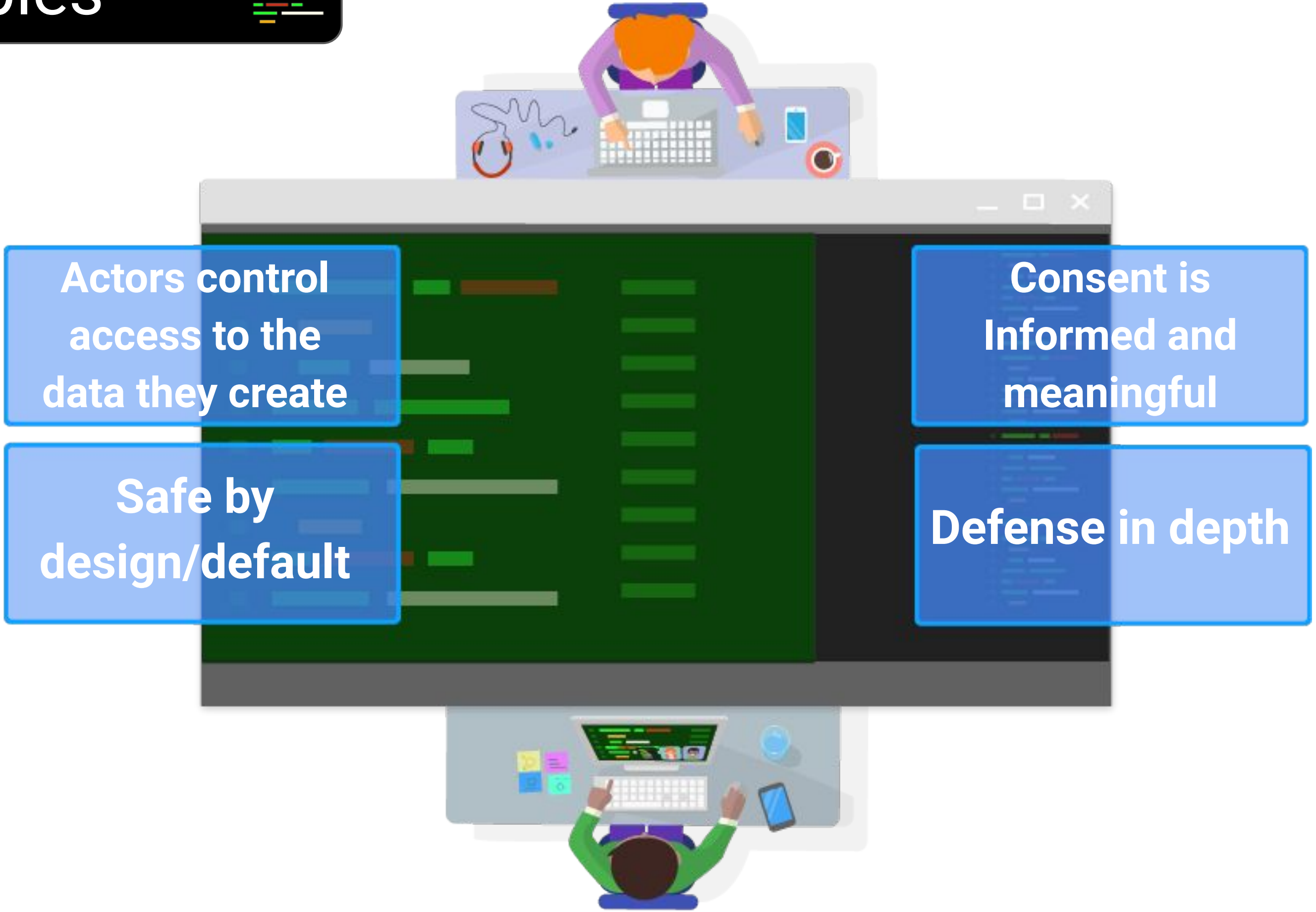
- Adversaries can get physical access to Android devices
  - Powered off
  - Screen locked
  - Screen unlocked by different user
  - Physical proximity
- Network communication and sensor data are untrusted
  - Passive eavesdropping
  - Active MITM

- Untrusted code is executed on the device
- Untrusted content is processed by the device
- **New**: **Insiders** can get access to signing keys

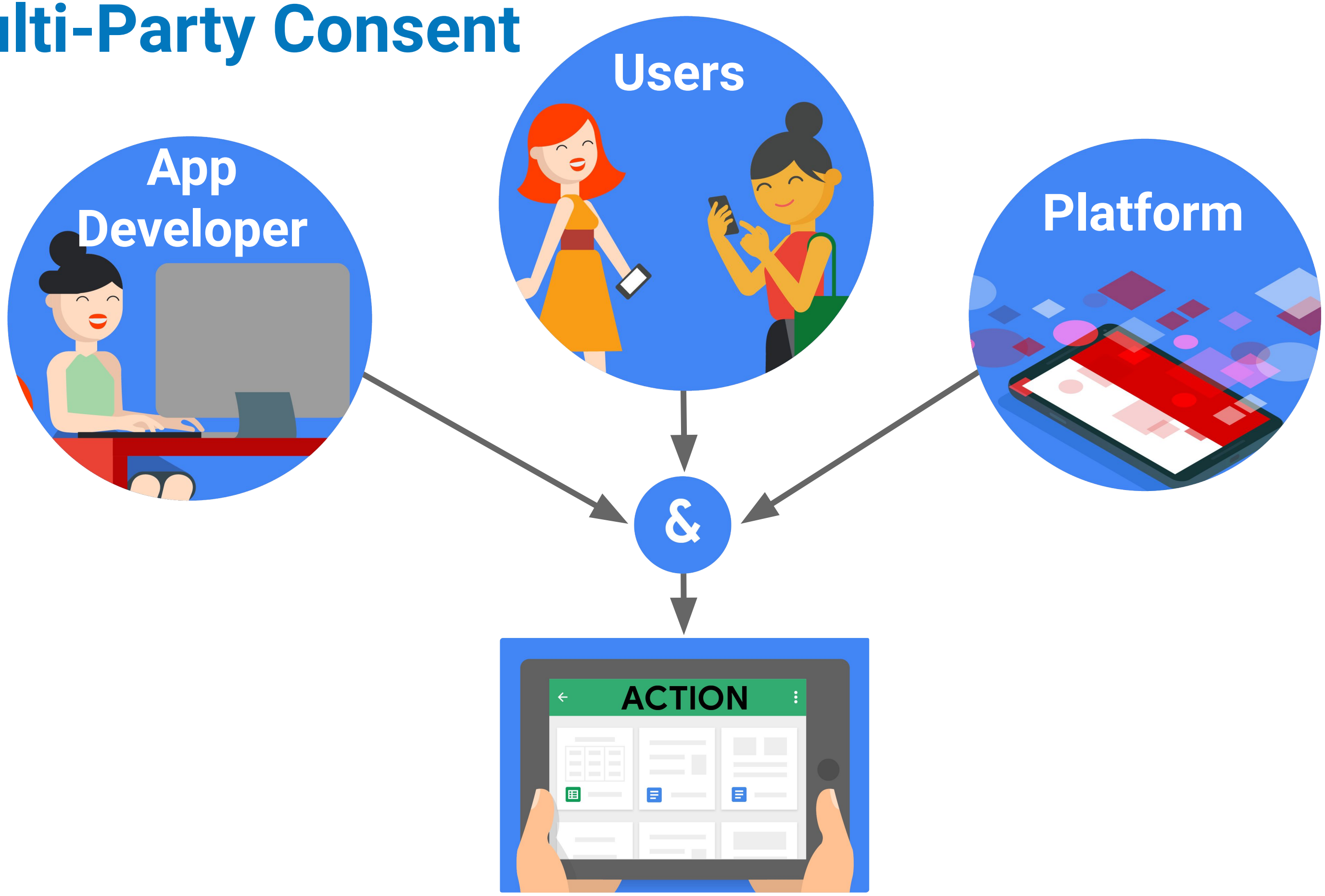
Google

[R. Mayrhofer. "*An architecture for secure mobile devices*", Security and Communication Networks, Volume 8 Issue 10, July 2015, pp. 1958-1970]

Principles


Actors control access to the data they create
Consent is Informed and meaningful
Safe by design/default
Defense in depth

The Android Platform Security Model
(1) Multi-Party Consent



Google

The Android Platform Security Model

(2) Open ecosystem access

(3) Security is a compatibility requirement

(4) Factory reset restores the device to a safe state

(5) Applications are security principals

Implementing the Security Model

[R. Mayrhofer, J. Vander Stoep, C. Brubaker, N. Kralevich. "*The Android Platform Security Model*', arXiv:1904.05572, April 2019, https://arxiv.org/abs/1904.05572]

Google

Strategies

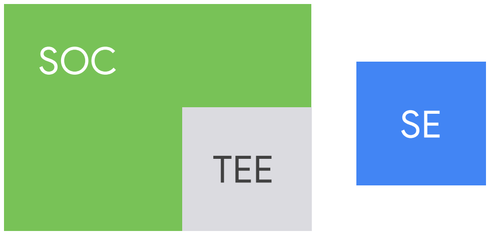
- **Contain**: isolating and de-privileging components, particularly ones that handle untrusted content.
    - **Access control**: adding permission checks, increasing the granularity of permission checks, or switching to safer defaults (for example, default deny).
    - **Attack surface reduction**: reducing the number of entry/exit points (i.e. principle of least privilege).
    - **Architectural decomposition**: breaking privileged processes into less privileged components and applying attack surface reduction.

→ **reduce reachability of code**

- **Mitigate**: Assume vulnerabilities exist and actively defend against classes of vulnerabilities or common exploitation techniques.

→ **reduce impact of reachable bugs**

It all starts with secure hardware



TEE (Trusted execution environment) used for key generation, key import, signing and verification services are executed in hardware.

.

Secure Lock Screen, PIN verification & Data encryption (PIN+HW key) used to derive encryption keys.

Version binding ensures keys created with a newer OS cannot be used by older OS versions.

Rollback prevention (8.0+) prevents downgrading OS to an older less secure version or patch level.

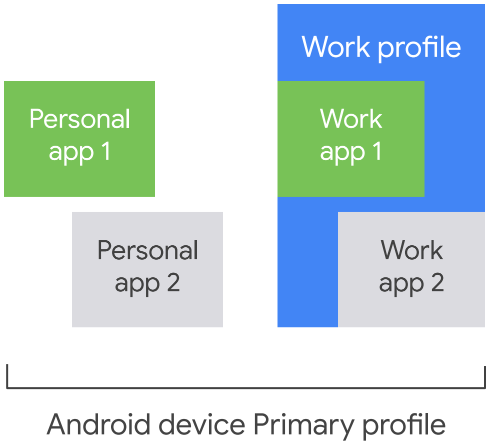
Verified Boot provides cryptographic verification of OS to ensure devices have not been tampered with.

Tamper-resistant hardware (Android Pie) offers support to execute cryptographic functions in dedicated hardware.

Question:

Make bootloader/verified boot state available to all apps?

SELinux, process isolation and sandboxing



Android is built on SELinux where if an exploit is found, the attack vector is limited to the domain the exploit is able to execute in.

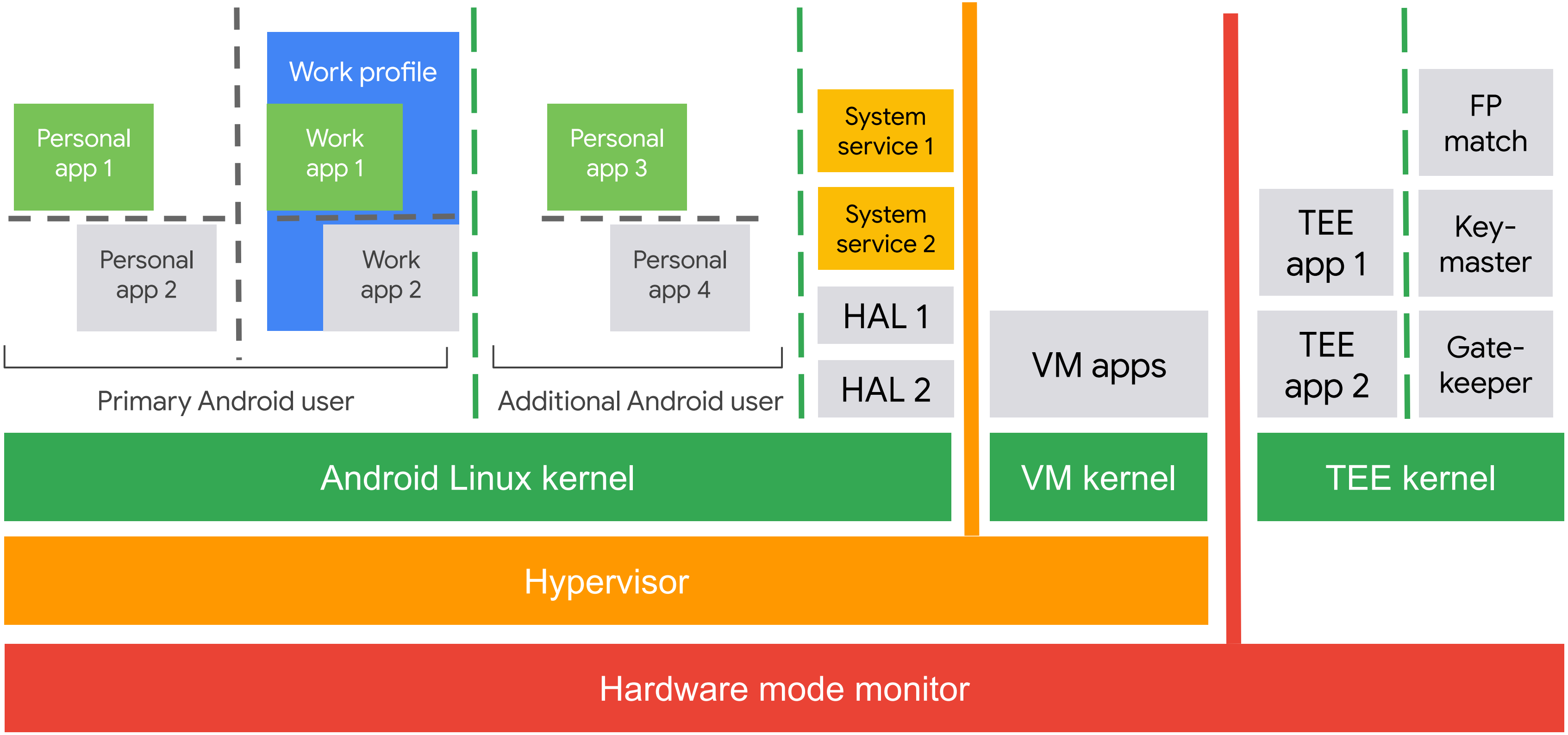
Application sandboxing ensures that application and system data is inaccessible from other apps. Each app runs in its own user ID (UID) - limiting exposure of apps to get data from one another.

Work profile apps are prevented from communicating with personal apps by default. Work profile apps run in a separate user space with separate encryption keys from personal apps, further limiting exposure, EMMs cannot manage the personal device when the device is managed only via the Work Profile.

Question:

Controlling device-wide parameters from profile owner?

Layers of containment on main AP



Question:

Dynamic SELinux policy update at run time?

Question:

Add another runtime permission for <X>?

Anti-exploitation

Bug = Exploit

ASLR/KASLR

Hardened ucopy

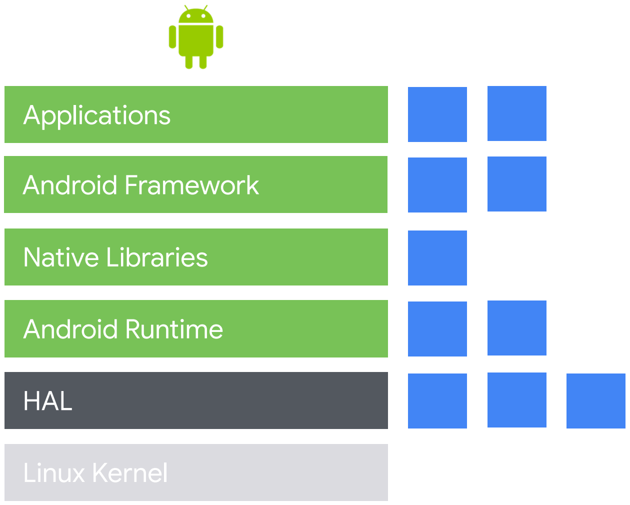
ASAN/Fuzzing

IOSan

CFI/KCFI

PAN

LTS



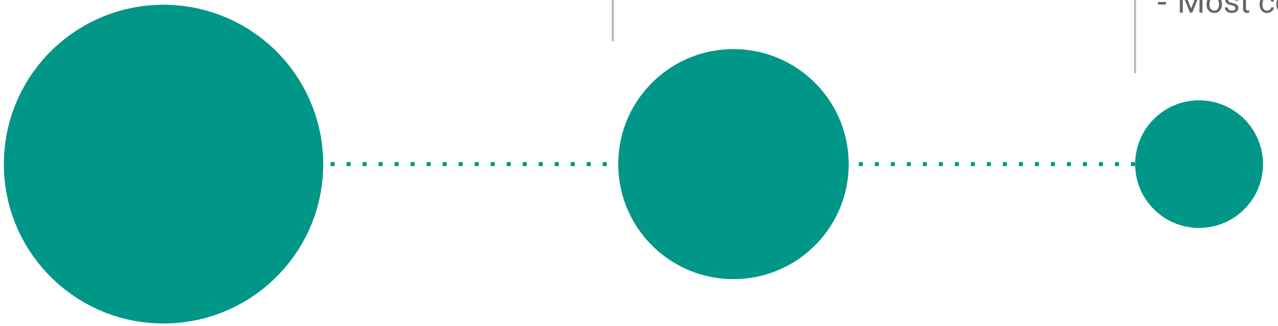
Google

The tiered authentication model

Primary Auth
- Knowledge-factor based
- Most secure

Secondary Auth
- Needs primary auth
- Less secure
- Somewhat constrained

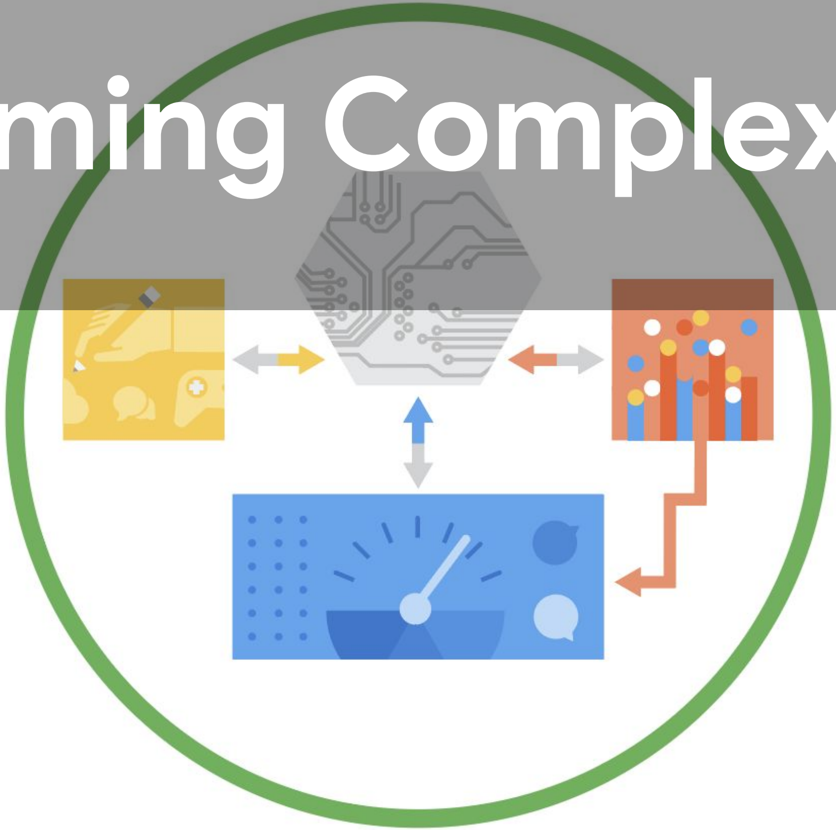
Tertiary auth
- Needs primary auth
- Least secure
- Most constrained



Question:

Expose authentication details to all apps?

Taming Complexity



Google

Many variants and stakeholders: Enabling an active ecosystem

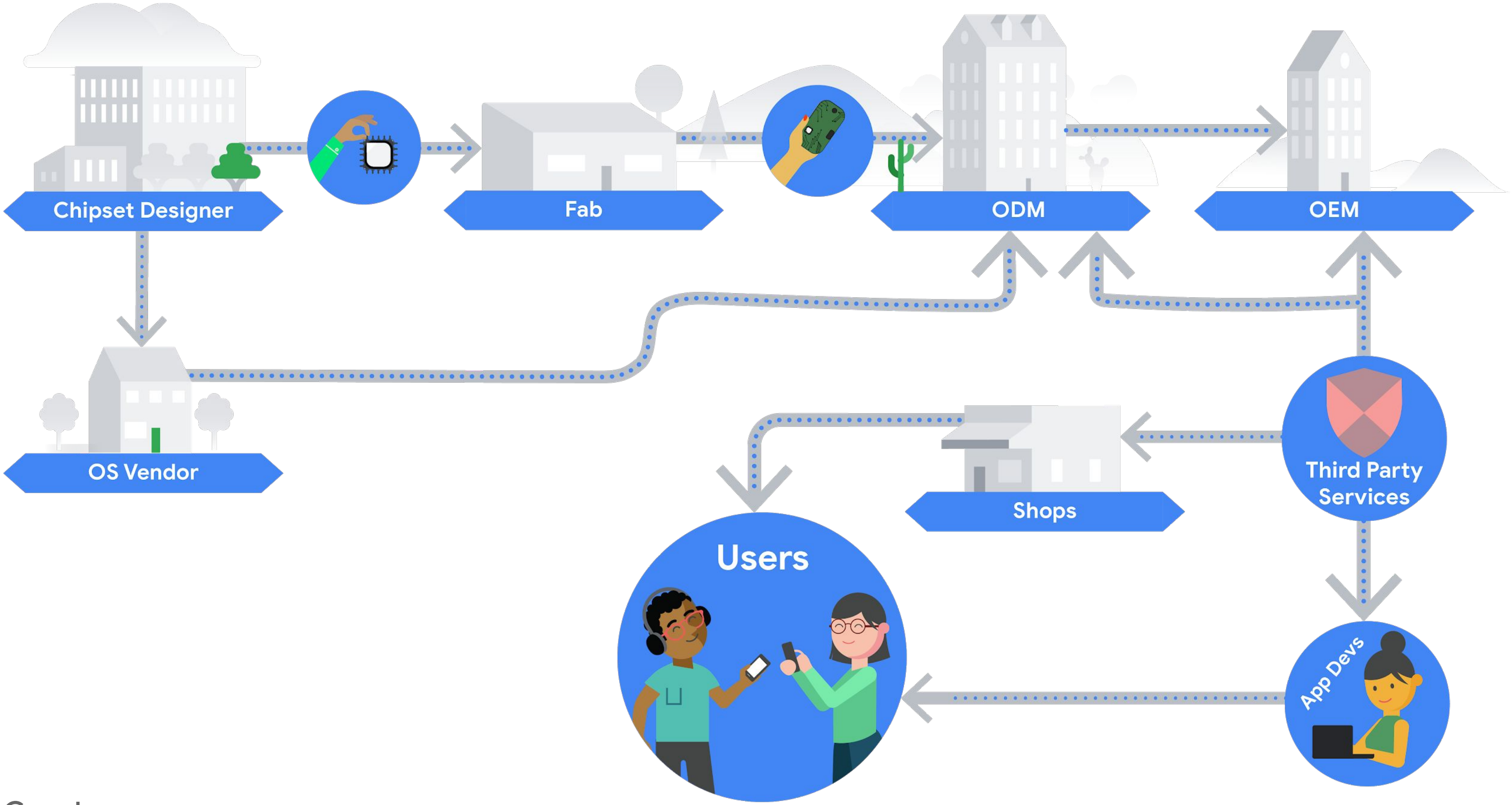
> 1.300 brands

> 24.000 devices

> 1 M apps

Can be written in any language

Google


Chipset Designer
Fab
ODM
OEM
OS Vendor
Third Party Services
Shops
Users
App Devs

Google

Question:

How many different platform signing keys?

Taming complexity in variants

Compatibility Definition Document (Standards)

- Defines requirements a device needs to fulfill to be considered "Android"
- Updated for every Android release
  - Many changes scoped to apps targeting this version
- Needs to strike a balance between strong standard base and openness for innovation
  - Some requirements scoped to hardware capabilities (e.g. form factors)
- Updating security requirements is one important means of driving ecosystem to improvement

Compatibility/Vendor/Security/... Test Suite (Enforcement)

- Tests need to be run by device menufacturer
- Guaranteed conformance to (testable parts of) CDD

  In Android Q, ca. ***800 tests for SELinux policy***

- Usability of Android trademark and Google apps bound to passing tests
- Complexity in test execution:
  - Automation of test cases
  - Visibility on "user" firmware builds

Question:

How quickly to change the requirements?

Changing the ecosystem is hard - Various strategies

1. Introducing new requirements initially as optional, becoming mandatory only in future releases → time for development, testing, adaptation

   Important lesson: **Clear communication of plans way ahead of schedule**

2. Ratcheting requirements from release to release with a pace that lets hardware keep up (including low-end devices and verticals) or keeping carve-outs

   Important lesson: **Let the tail end of the ecosystem keep up**

Google

100%

of compatible devices launching with Q will **encrypt user data**

Strong

SAR: 0-7%
Pipeline: Secure

- 72-hours before fallback to primary auth
- Application integration via BiometricPrompt, FIDO2, or custom APIs

Weak

SAR: 7-20%
Pipeline: Secure

- 12 hours before fallback to primary auth
- No application integration of any kind.

Convenience

SAR: >20%
Pipeline: (In)secure

- 4 hours before fallback to primary auth
- No application integration of any kind.

Google

Strong

SAR: 0-7%
Pipeline: Secure

- 72-hours before fallback to primary auth
- Application integration via BiometricPrompt, FIDO2, or custom APIs

Weak

SAR: 7-20%
Pipeline: Secure

- 12 hours before fallback to primary auth
- No application integration of any kind.

Convenience

SAR: >20%
Pipeline: (In)secure

- 4 hours before fallback to primary auth
- No application integration of any kind.

Target API version requirements

Actively maintained apps (forefront) in Play

August 2019: New apps are required to target API level 28 (Android 9) or higher.
November 2019: Updates to existing apps are required to target API level 28 or higher.

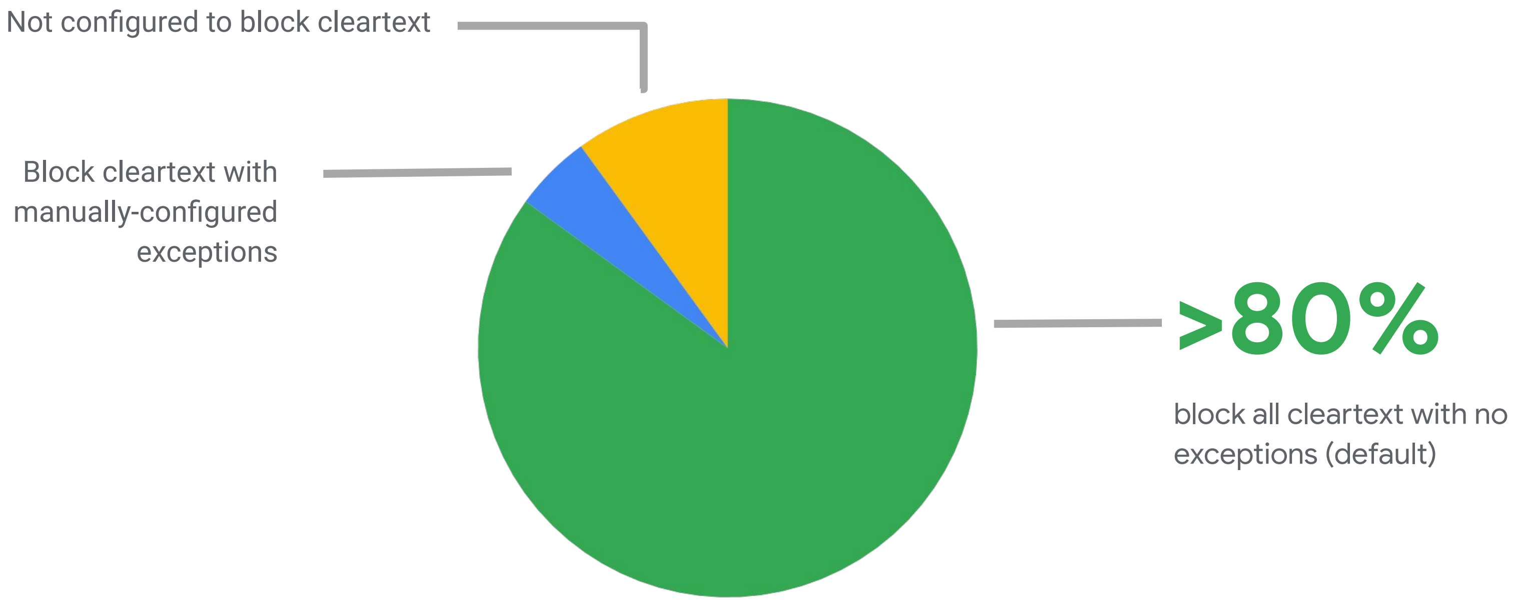
Apps not getting updates (tail end) on device

August 2019: New apps will receive warnings during installation if they do not target API level 26 or higher.
November 2019: New versions of existing apps will receive warnings during installation if they do not target API level 26 or higher.

Google

https://android-developers.googleblog.com/2019/02/expanding-target-api-level-requirements.html

Apps targeting Pie, usage of `NetworkSecurityConfig`



Source: Google Internal Data, 2019-04-01

Taming complexity in stakeholders

Tooling

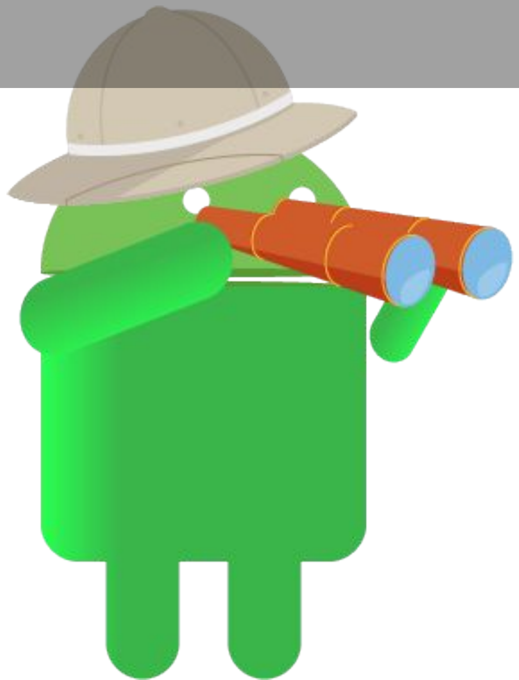
- Compiler/build toolchain ideally used by all stakeholders (e.g. drivers, TrustZone, etc. code)
- Can add new mitigations at this level, but *typically breaks old code*

Upstream first approach

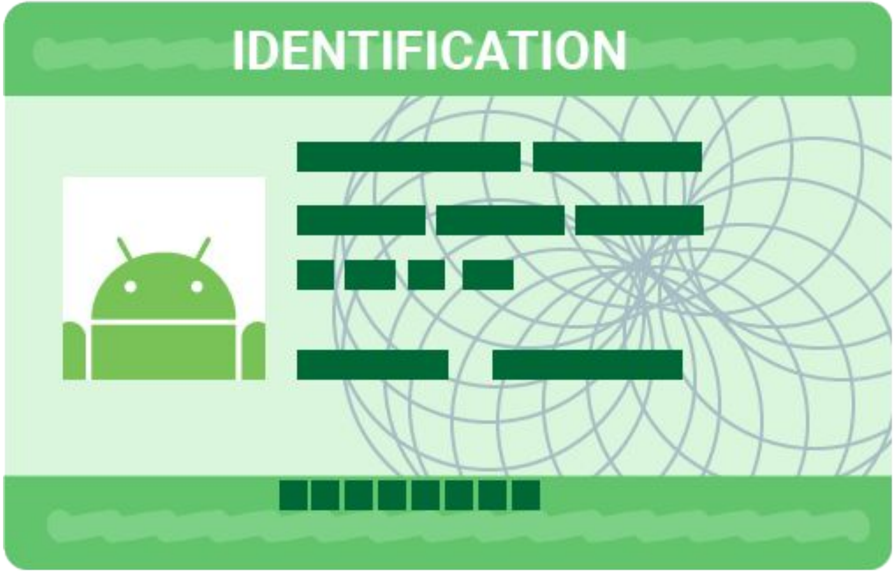
- Importance to commit changes to common upstream code (e.g. Linux kernel, clang, etc.)
- Encouraging other stakeholders to upstream their changes (either to common upstream or to AOSP)

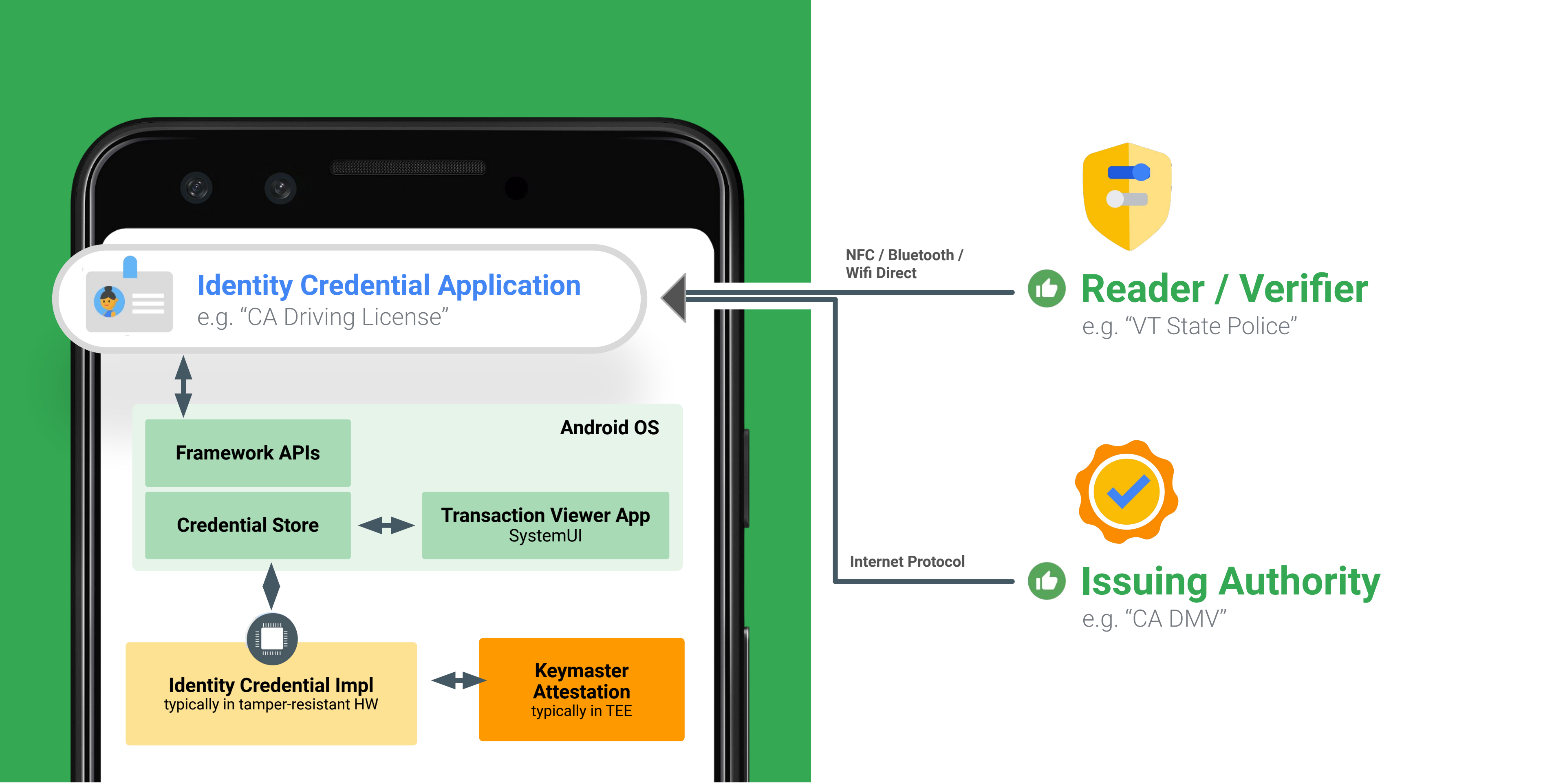
Open source and common issue trackers

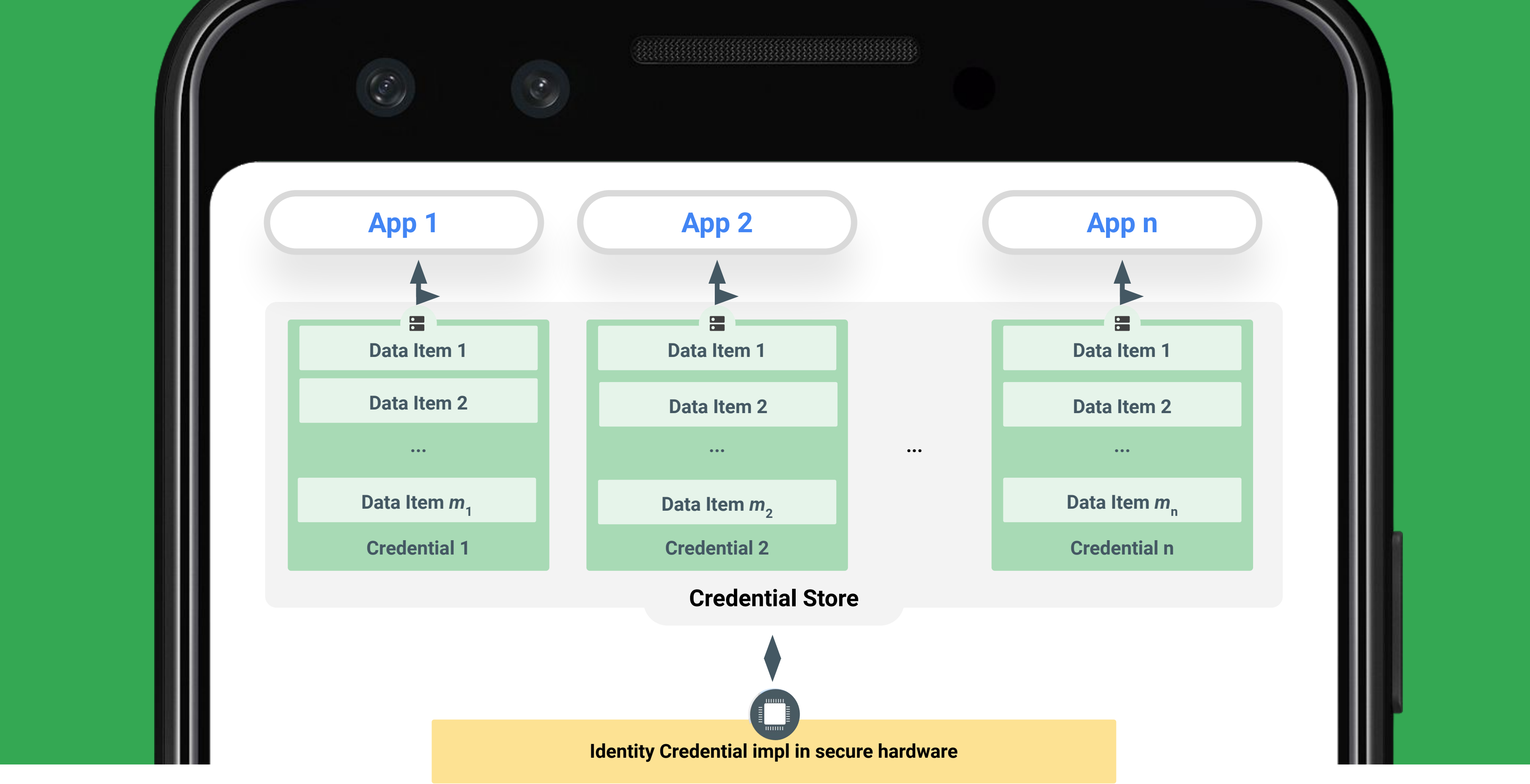
Where do we go from here?



Identity Credentials




Identity Credential Application
e.g. "CA Driving License"
Android OS
Framework APIs
Credential Store
Transaction Viewer App
SystemUI
Identity Credential Impl
typically in tamper-resistant HW
Keymaster
Attestation
typically in TEE
NFC / Bluetooth /
Wifi Direct
Reader / Verifier
e.g. "VT State Police"
Internet Protocol
Issuing Authority
e.g. "CA DMV"



App 1
App 2
App n
Data Item 1
Data Item 2
...
Data Item m_1
Credential 1
Data Item 1
Data Item 2
...
Data Item m_2
Credential 2
...
Data Item 1
Data Item 2
...
Data Item m_n
Credential n
Credential Store
Identity Credential impl in secure hardware

Security and Privacy for draft mDL standard

- **Security** properties:
  - **Anti-forgery**: Identity Credential data is signed by the Issuing Authority
  - **Anti-cloning**: Secure Hardware produces MAC during provisioning using a key derived from a private key specific to the credential and an ephemeral public key from the reader. Public key corresponding to credential private key is signed by the Issuing Authority
  - **Anti-eavesdropping**: Communications between Reader/Verifier and Secure Hardware are encrypted and authenticated
- **Privacy** properties:
  - **Data minimization**: Reader/Verifier only receives data consented to by the holder. Backend infrastructure does not receive information about use
  - **Unlinkability**: Application may provision single-use keys
  - **Auditability**: Every transaction and its data is logged and available only to the Holder (not the application performing the transaction)

Question:

Strictly require secure (certified) hardware?

Status

Android Q

- No changes to platform itself
- Software implementation as compatibility library

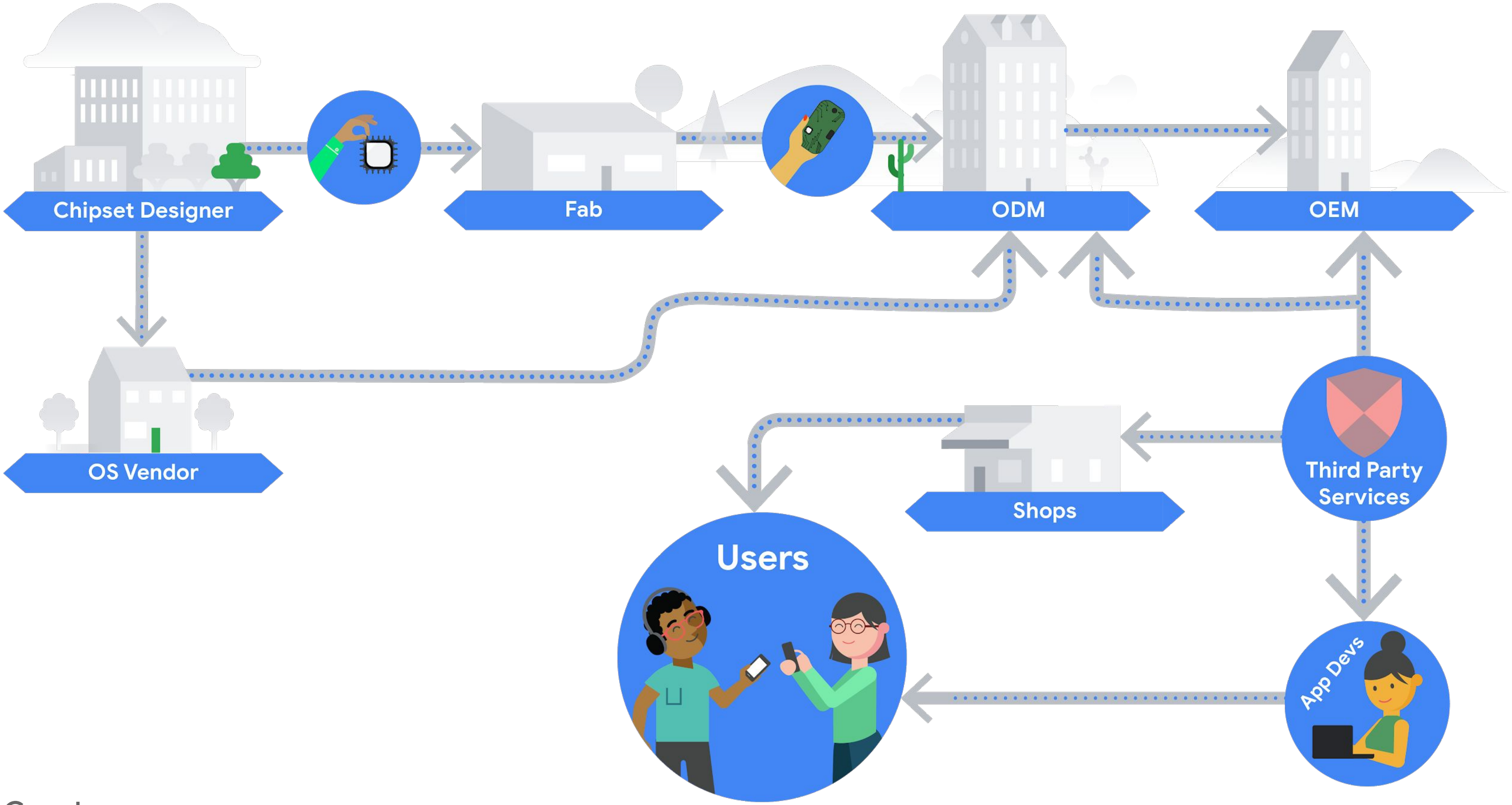
```
SecurityType = SOFTWARE_ONLY
CertificationLevel = NONE
```

- Can start developing identity apps, library will be compatible with vast majority of Android devices

Future versions

- HAL implementation based on secure hardware
- Optional **Direct Access** support
- Credential Store system daemon
- Framework APIs

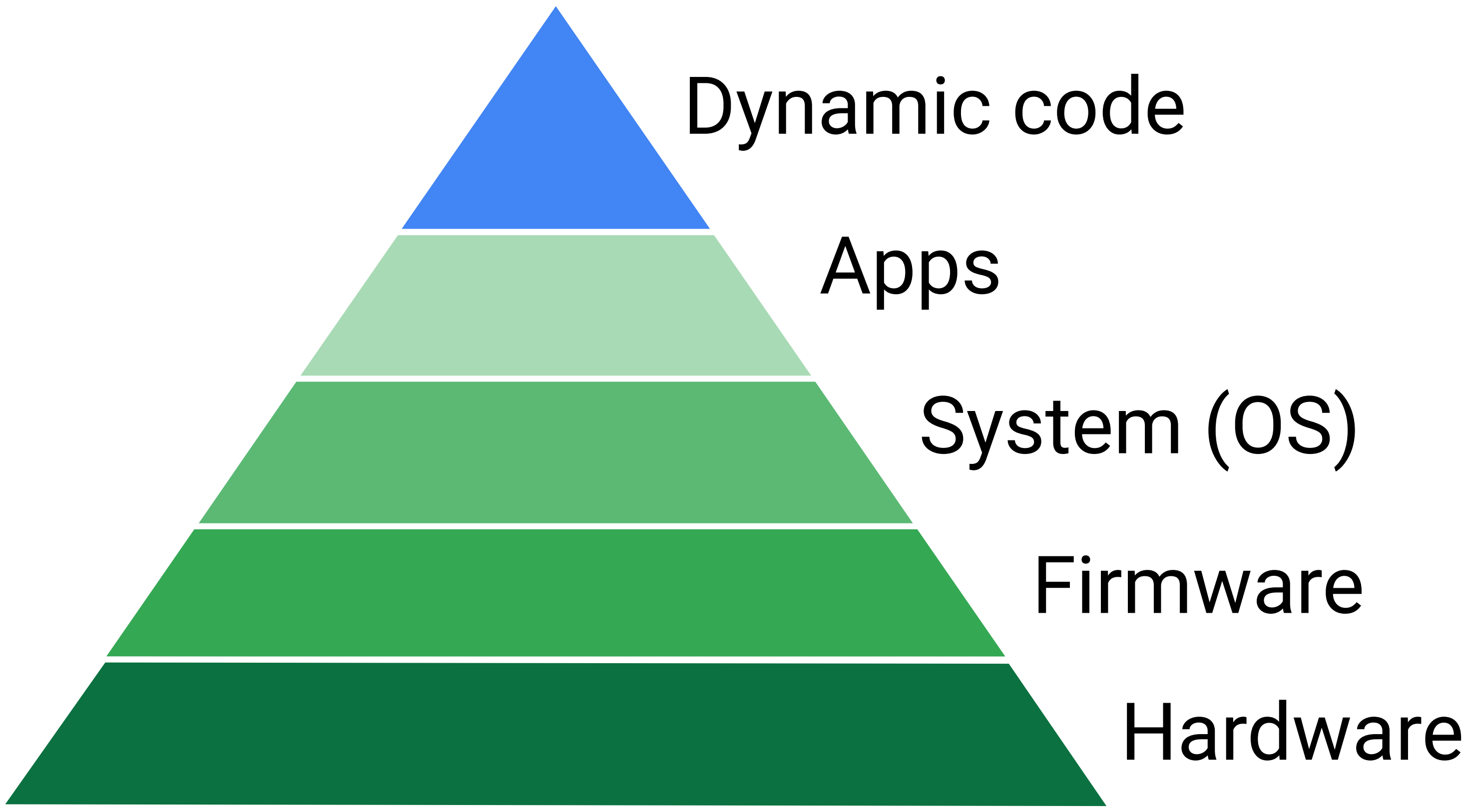

Insiders



Chipset Designer
Fab
ODM
OEM
OS Vendor
Third Party Services
Shops
Users
App Devs

Google

Simple and few trusted components

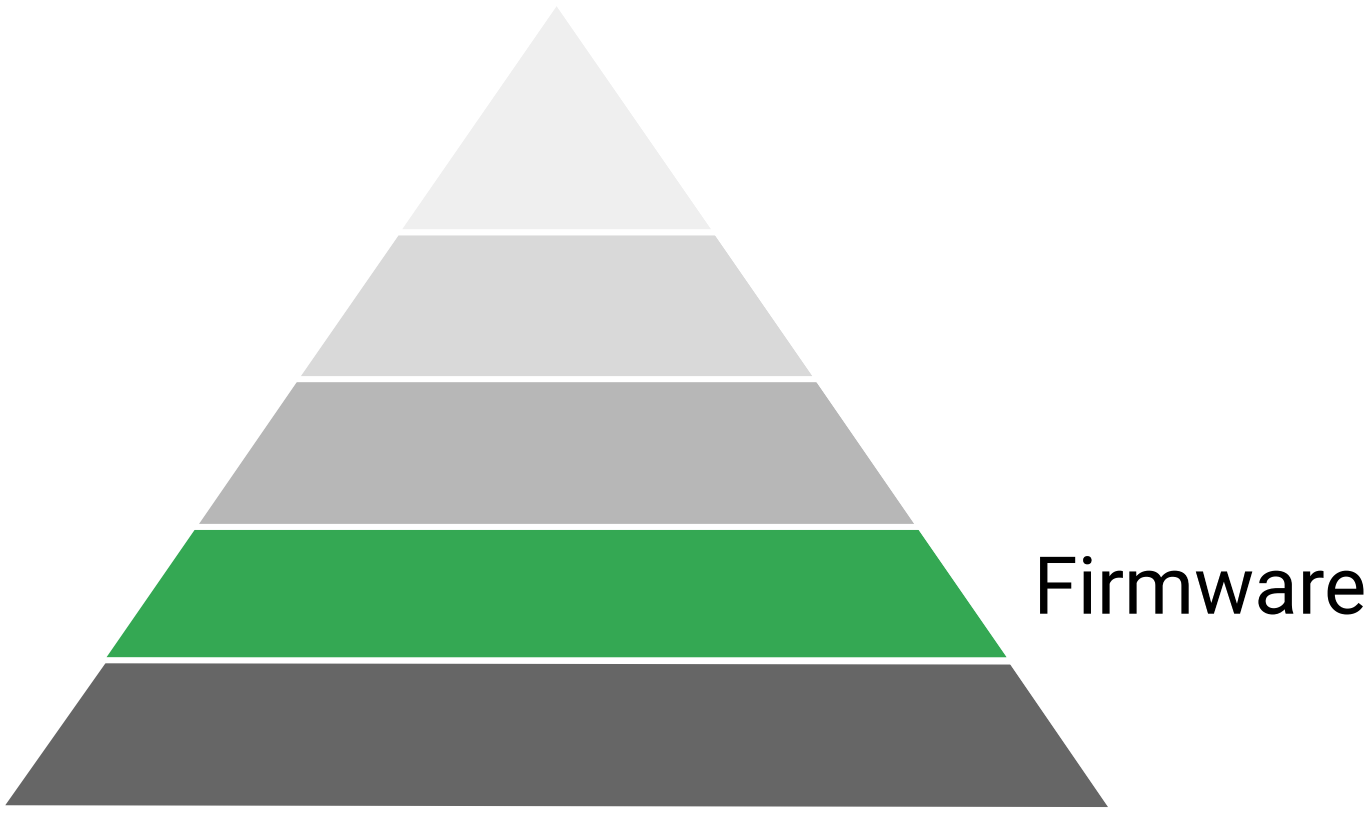

Dynamic code
Apps
System (OS)
Firmware
Hardware


Hardware

Threat models / scenarios for hardware security

- **Basic** assumption for hardware security:
  - Adversary has possession of the hardware
  - Adversary has control over all network channels
  - Adversary can influence sensor readings/input
- **Intermediate** assumptions:
  - Side channel analysis: including power, RF, timing, and potentially others
  - Side channel injection: including power, clock, RF (up to laser), and potentially others
  - Reverse engineering of hardware
  - Modification of hardware on PCB level, but not chip level
- **Advanced** assumptions:
  (AKA nation state adversaries or **insider** threats)
  - Modification of hardware on chip level
  - Access to internal signing keys

Open research question: Transparency and meaningful auditability for hardware components



Google

Wipe on firmware update without user involvement

[C-SR] are **STRONGLY RECOMMENDED** to provide **insider attack resistance (IAR)**, which means that an insider with access to firmware signing keys cannot produce firmware that causes the StrongBox to leak secrets, to bypass functional security requirements or otherwise enable access to sensitive user data. The recommended way to implement IAR is to **allow firmware updates only when the primary user password is provided** via the IAuthSecret HAL. IAR **will likely become a requirement in a future release**.

https://android-developers.googleblog.com/2018/05/insider-attack-resistance.html
https://source.android.com/compatibility/9.0/android-9.0-cdd Section 9.11.2. StrongBox

Insider Attack Resistance for user PIN/password/pattern

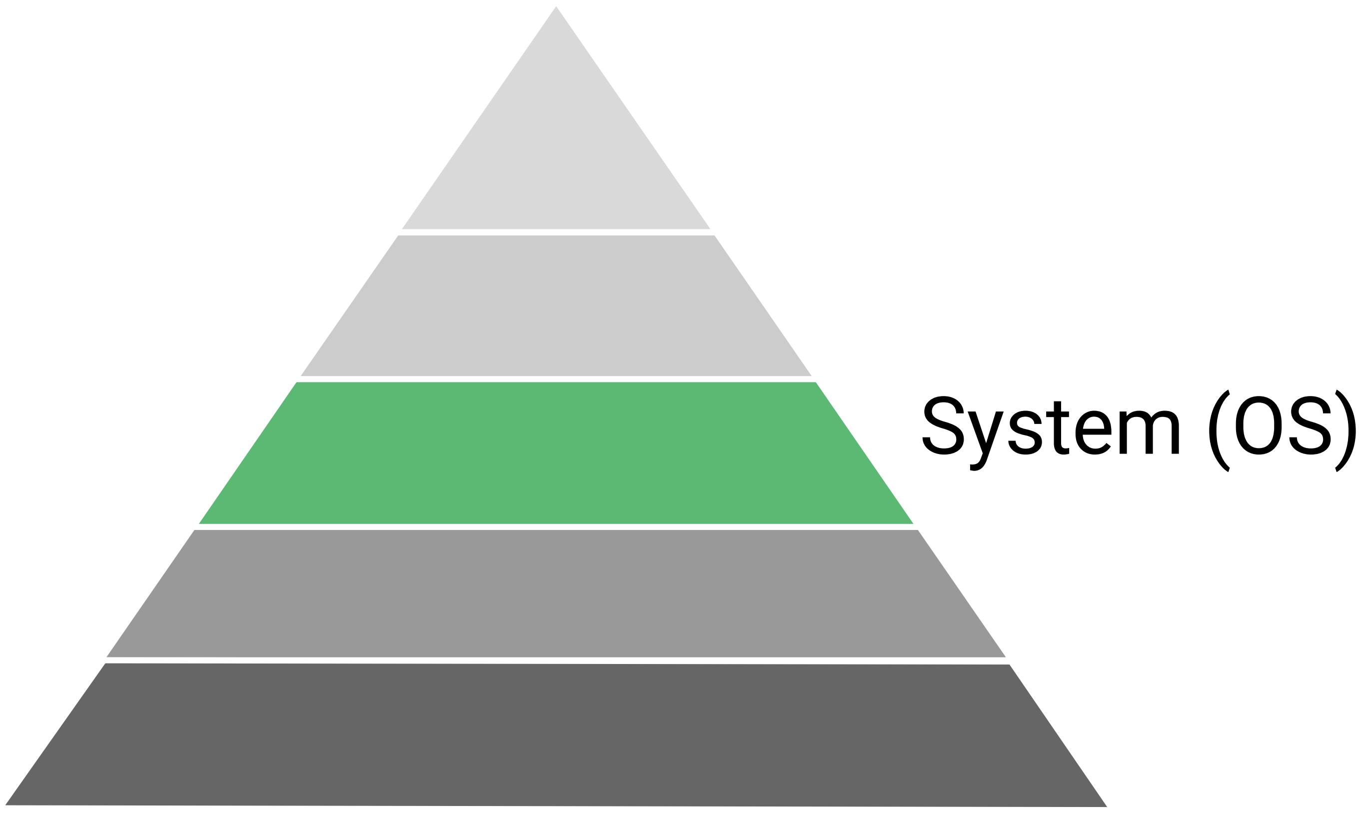
Google Pixel 2 (Weaver)

- Javacard applets on NXP secure element hold secrets and compare user knowledge factor
- Explicitly **doesn't implement data backup functionality**
- If app is updated, secrets are wiped
- NXP SE **OS upgrade itself requires app to be uninstalled**, wiping secrets.
- If a new app is needed, it's installed alongside the old, and secrets are migrated when used.

Google Pixel 3 (Weaver and Strongbox)

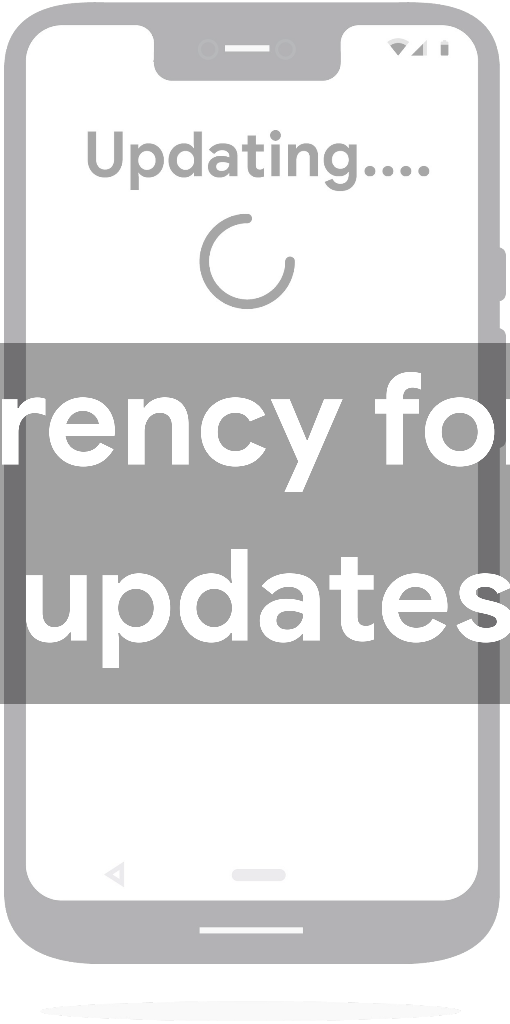
- Custom firmware on Google Titan M
- Firmware update is atomic with A/B (active/inactive) slots
- **Any new firmware is put into untrusted "hold" state** during installation to inactive slot
- Only providing matching **user knowledge factor transitions it into trusted active slot**
- Resetting knowledge factor (e.g. for RMA) forces wiping secrets beforehand

https://www.blog.google/products/pixel/titan-m-makes-pixel-3-our-most-secure-phone-yet/



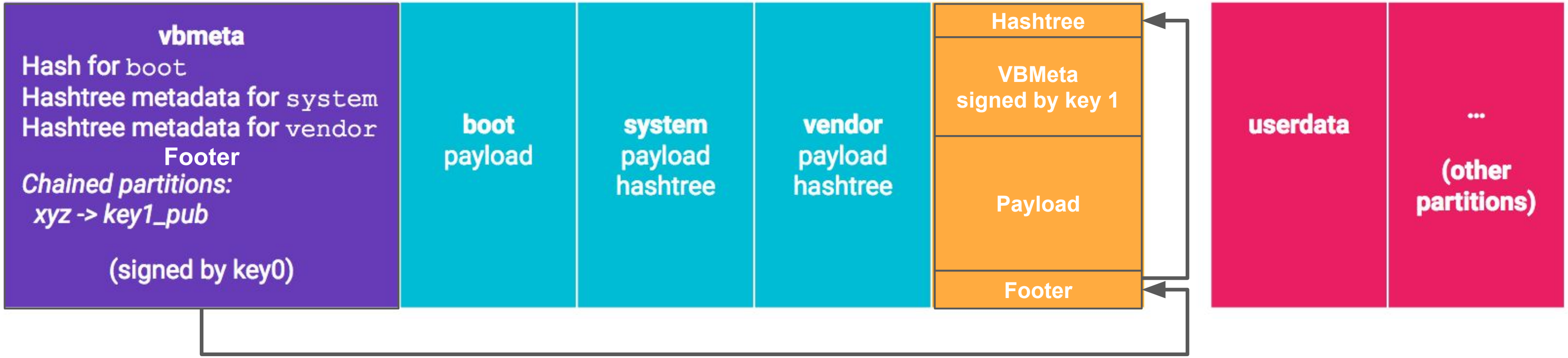
Google

Transparency for system updates



Android Verified Boot (AVB) / VBMeta

- AVB uses VBMeta structures to describe/verify elements of the boot chain.
- Bootloader stores hash measurement of VBMeta into KeyMaster v4
- VBMeta lives either in its own partition or on chained partitions
- The hash of VBMeta can be remotely attested with Key Attestation



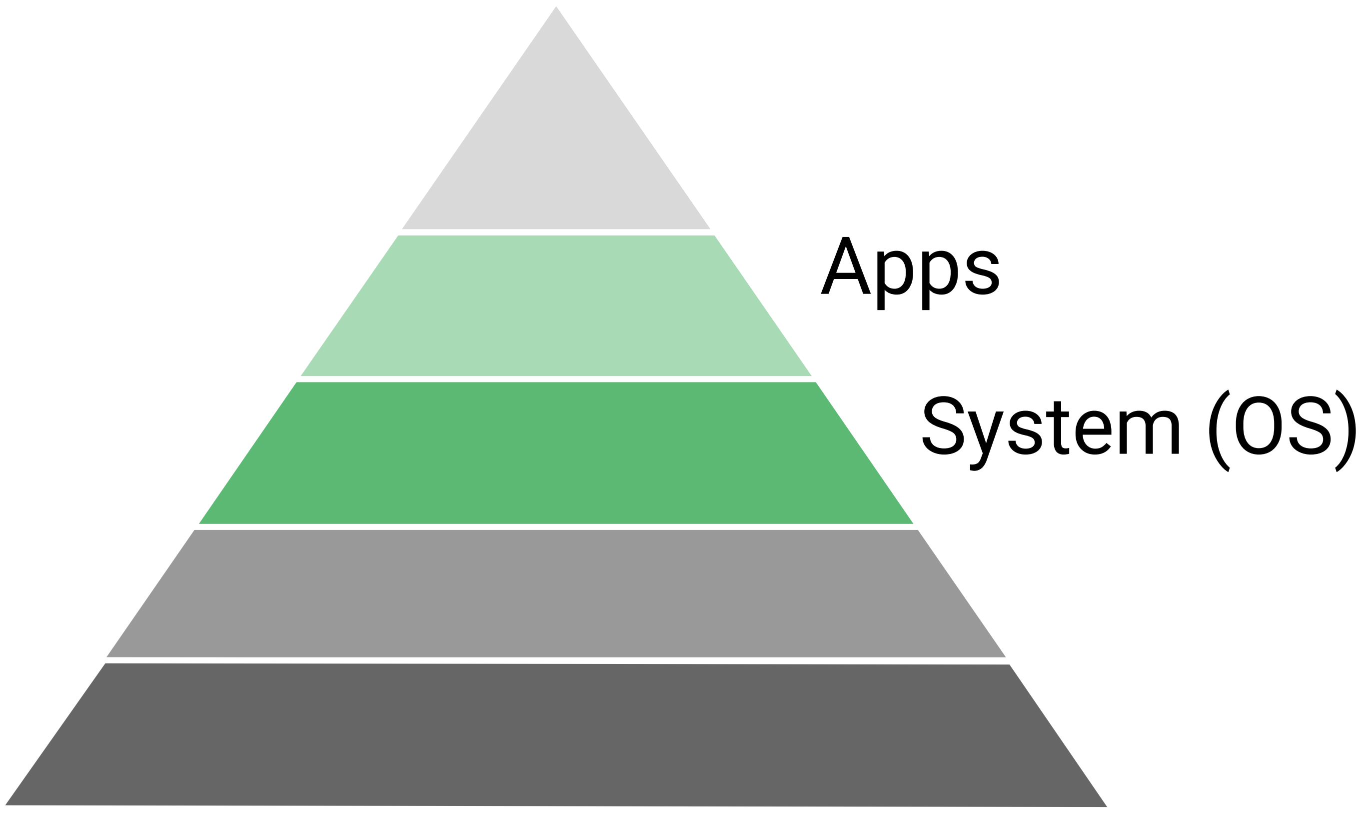
https://android.googlesource.com/platform/external/avb/
https://developers.google.com/android/images

VBMeta digest verification

Getting reference VBMeta digest

Attestation and verification of VBMeta digest

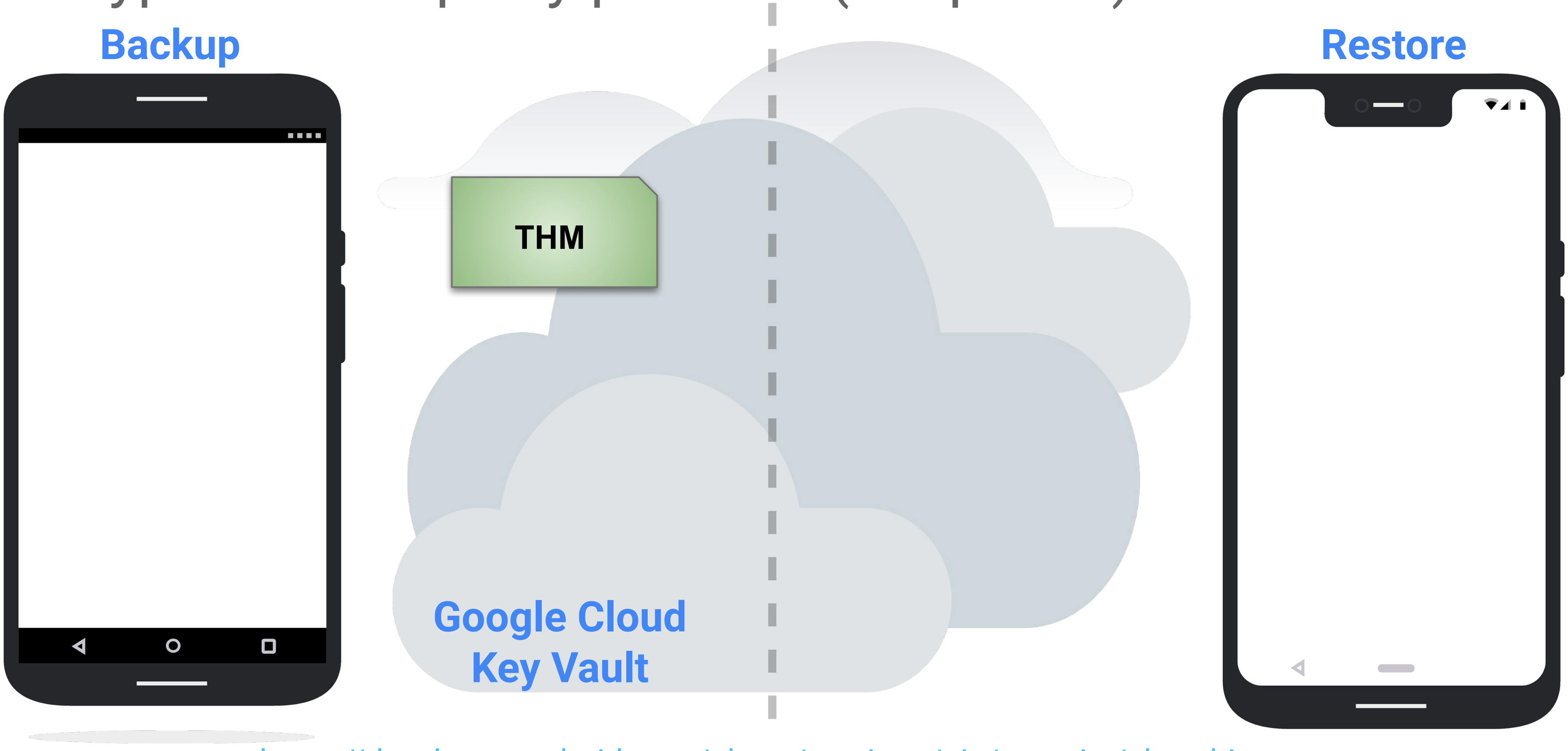
https://android.googlesource.com/platform/external/avb/
https://developers.google.com/android/images



Google

End-to-end backup encryption

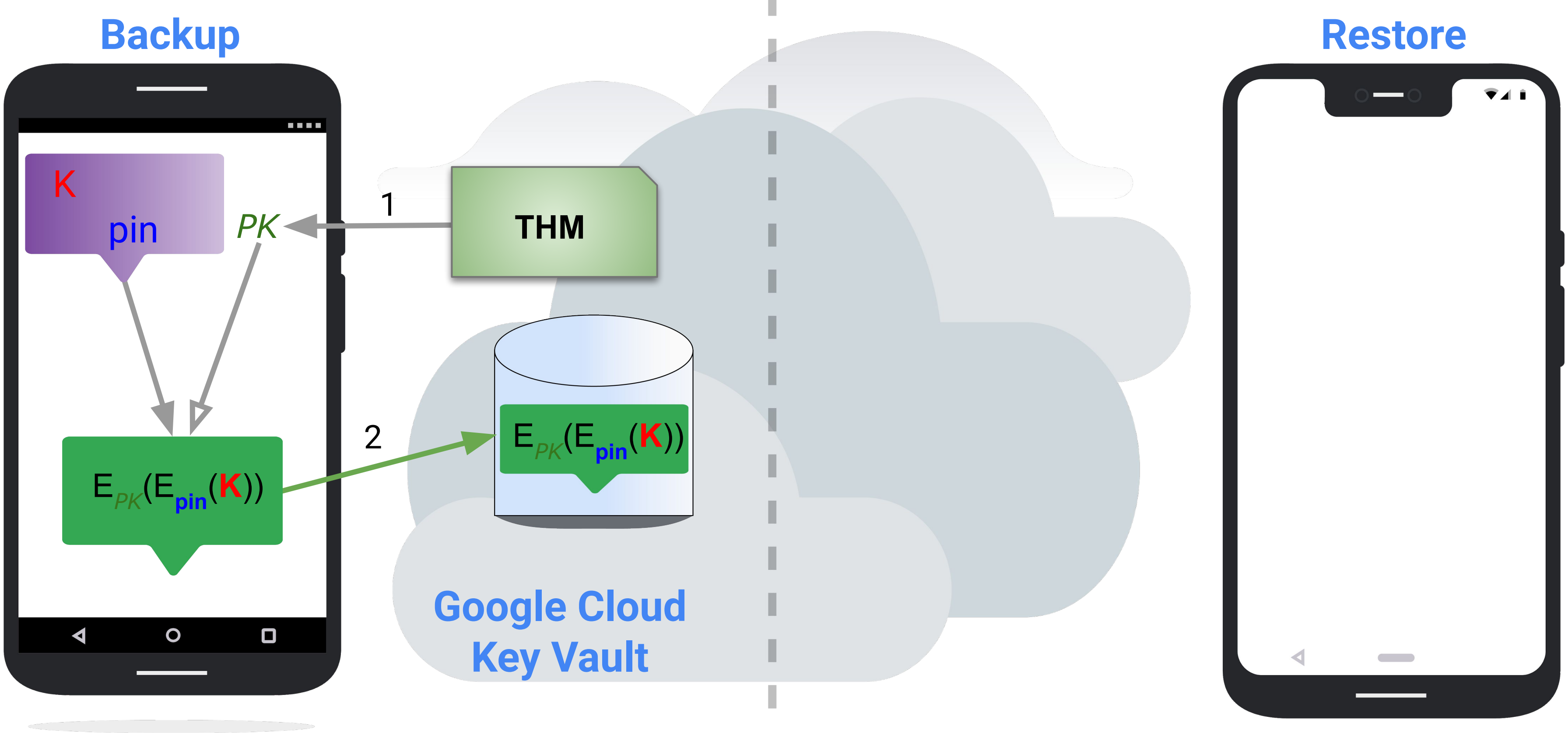
Encrypted backup key protocol (simplified)



Google

https://developer.android.com/about/versions/pie/security/ckv-whitepaper
https://security.googleblog.com/2018/10/google-and-android-have-your-back-by.html

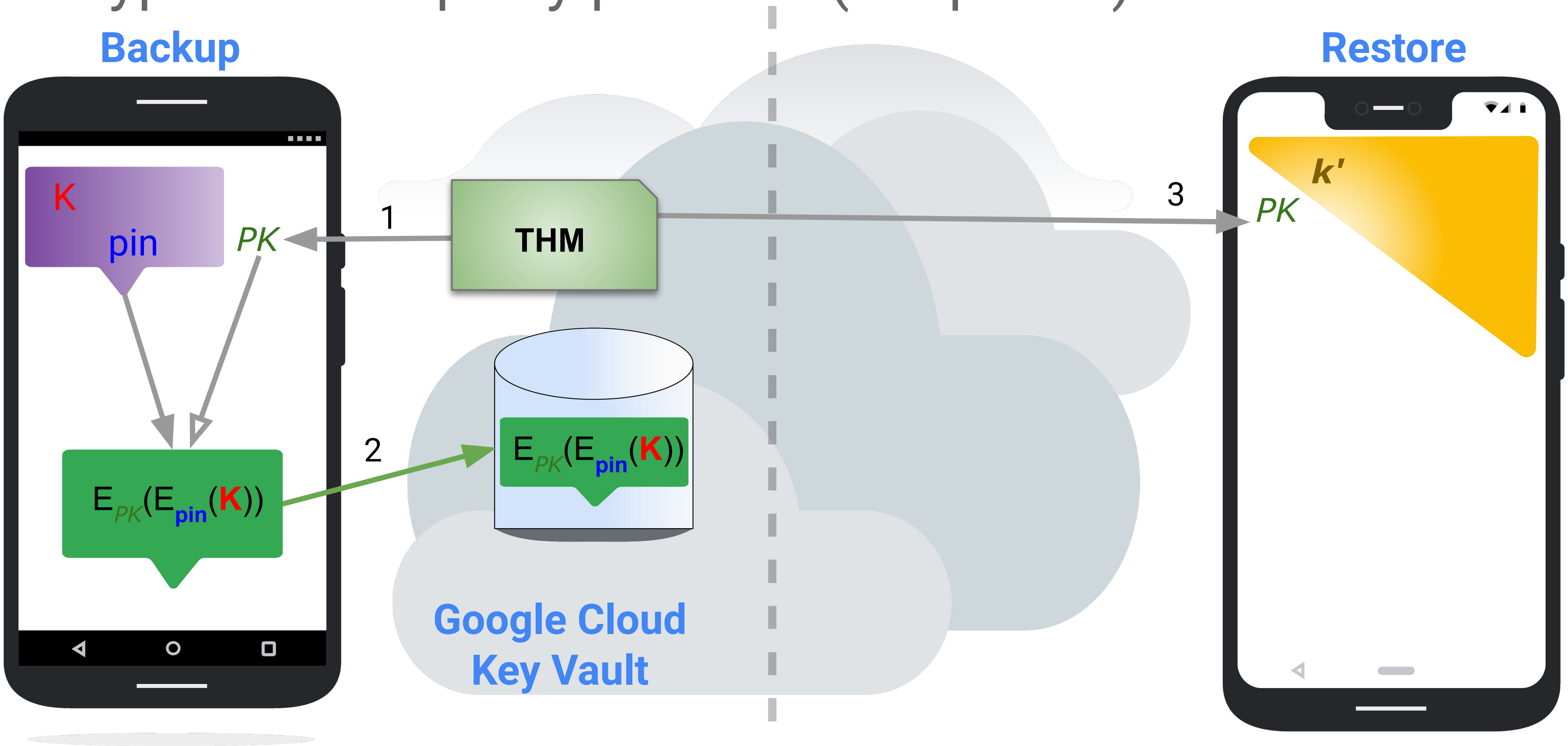
Encrypted backup key protocol (simplified)



https://developer.android.com/about/versions/pie/security/ckv-whitepaper
https://security.googleblog.com/2018/10/google-and-android-have-your-back-by.html

Google

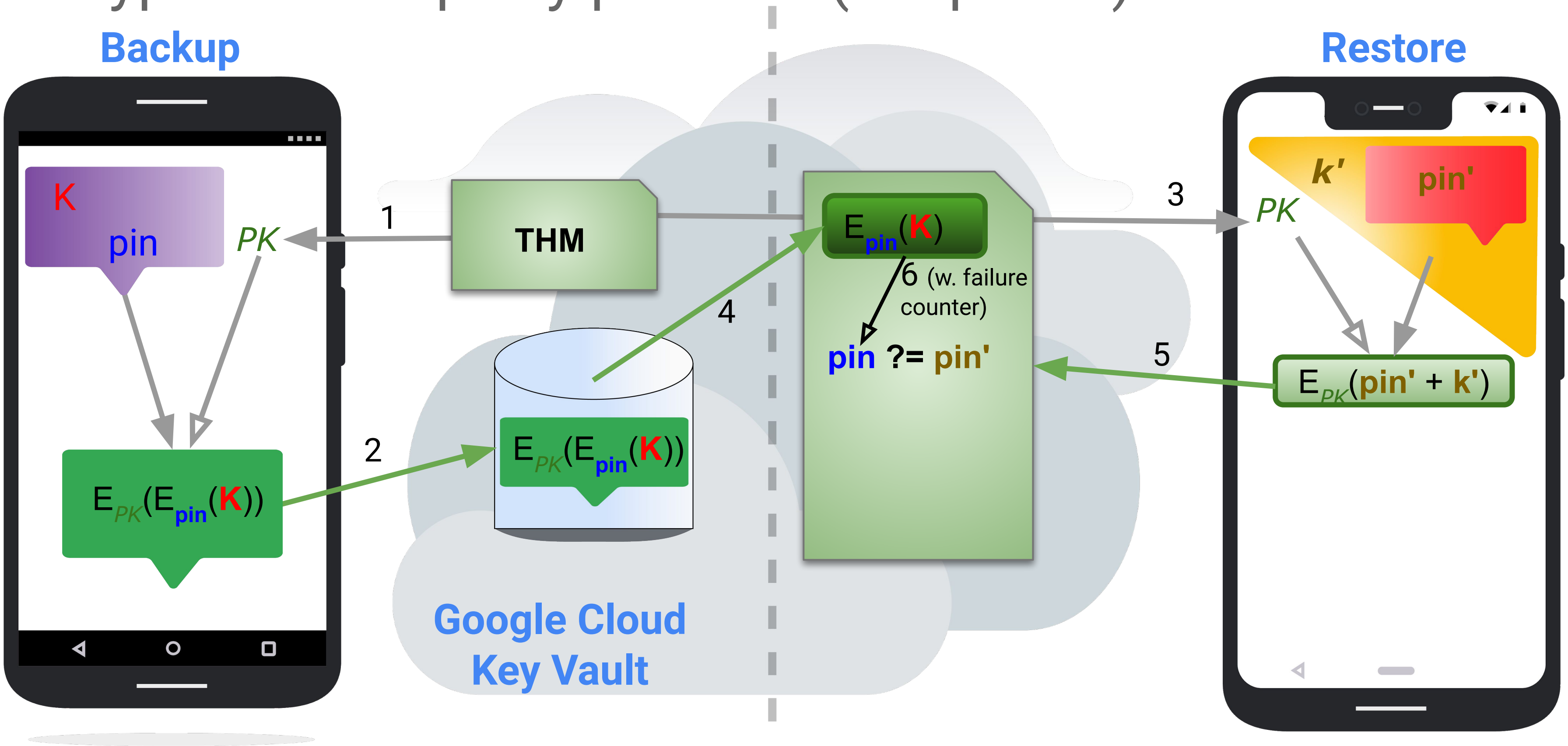
Encrypted backup key protocol (simplified)



Google

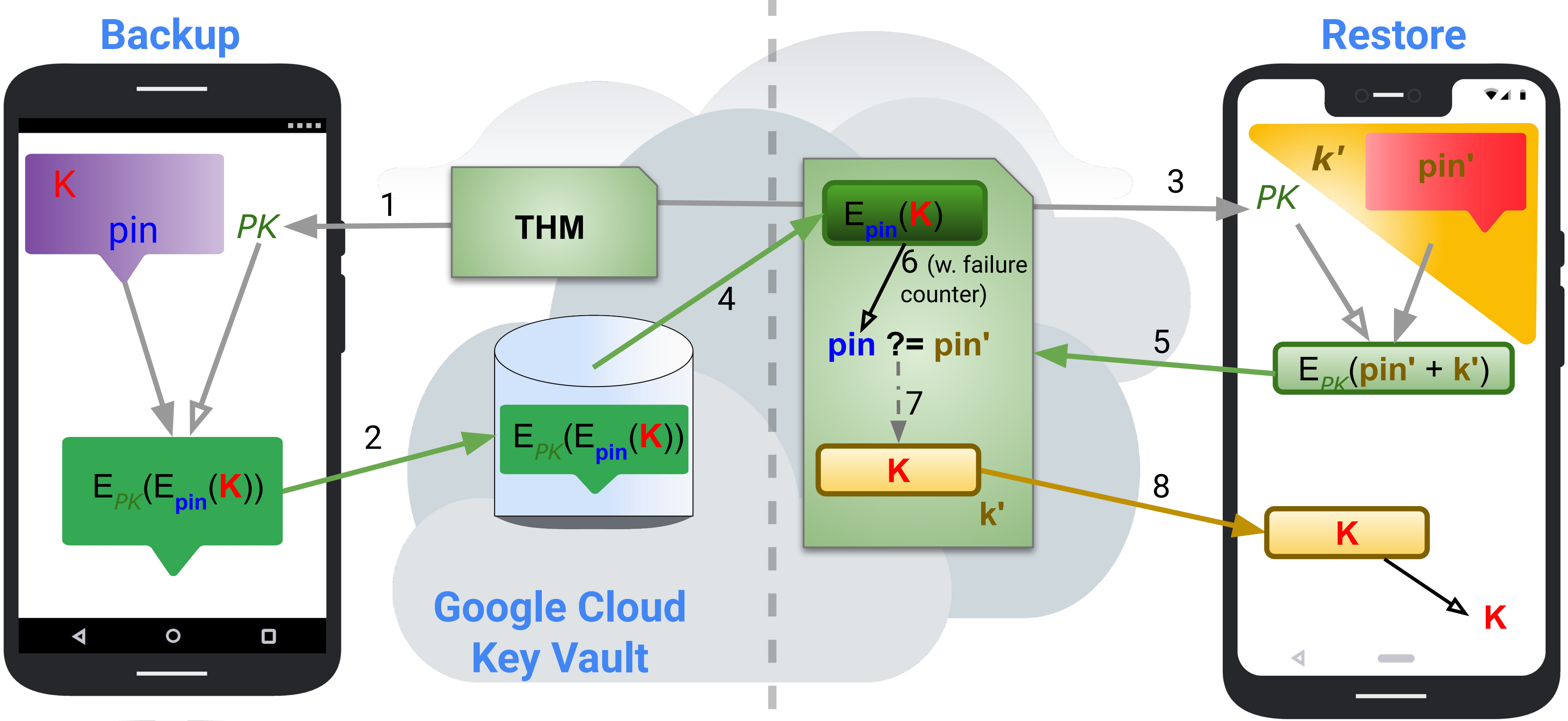
https://developer.android.com/about/versions/pie/security/ckv-whitepaper
https://security.googleblog.com/2018/10/google-and-android-have-your-back-by.html

Encrypted backup key protocol (simplified)



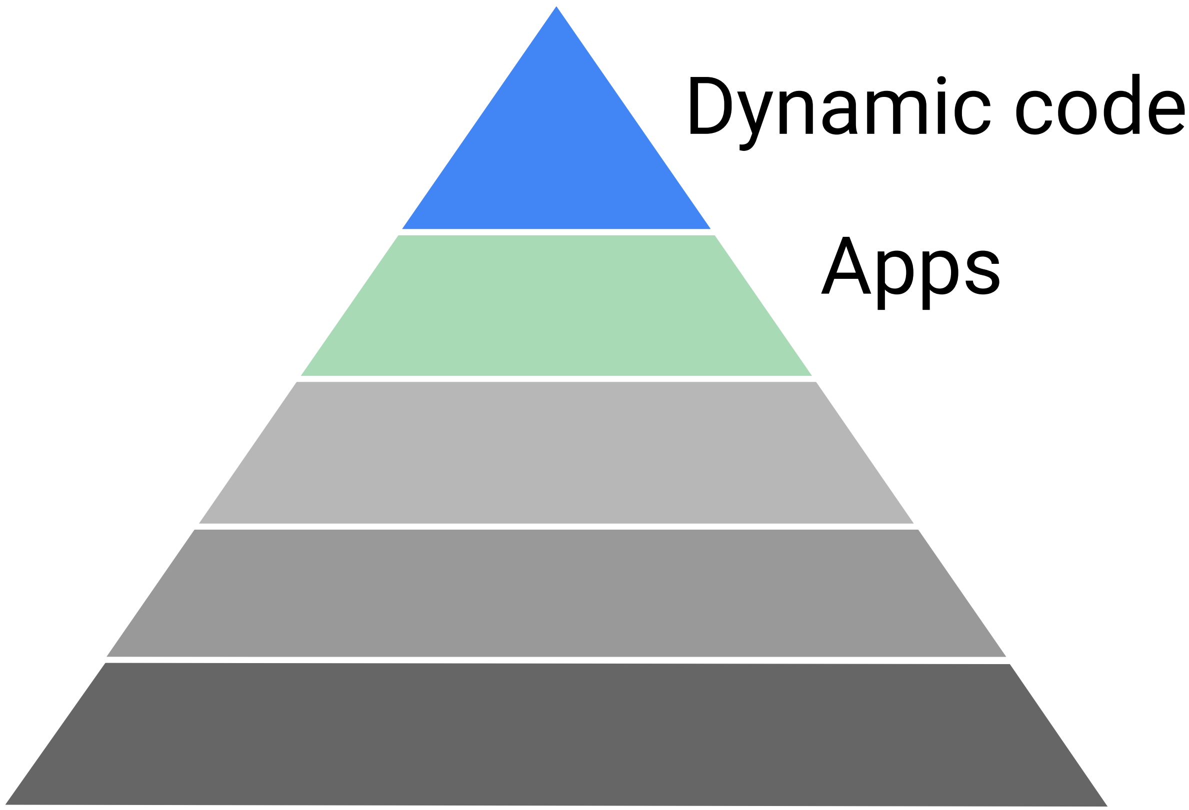
https://developer.android.com/about/versions/pie/security/ckv-whitepaper
https://security.googleblog.com/2018/10/google-and-android-have-your-back-by.html

Encrypted backup key protocol (simplified)



Google

https://developer.android.com/about/versions/pie/security/ckv-whitepaper
https://security.googleblog.com/2018/10/google-and-android-have-your-back-by.html


Dynamic code
Apps

Auditability is a key defense against insider attacks

Don’t take my word for it

(Some) Resources

- https://www.android.com/security-center/
- https://source.android.com/security
- https://developer.android.com/training/articles/security-tips
- https://arxiv.org/abs/1904.05572
- https://source.android.com/security/reports/Google_Android_Enterprise_Security_Whitepaper_2018.pdf
- https://android-developers.googleblog.com/search/label/Security
- https://android-developers.googleblog.com/2019/05/whats-new-in-android-q-security.html
- https://android-developers.googleblog.com/2018/12/android-pie-la-mode-security-privacy.html
- https://www.google.com/about/appsecurity/research/presentations/
- https://www.mayrhofer.eu.org/post/android-tradeoffs-0-meta/
- https://www.mayrhofer.eu.org/post/android-tradeoffs-1-rooting/
- https://www.blackhat.com/docs/us-17/thursday/us-17-Kralevich-Honey-I-Shrunk-The-Attack-Surface-Adventures-In-Android-Security-Hardening.pdf
- https://www.blackhat.com/docs/us-16/materials/us-16-Kralevich-The-Art-Of-Defense-How-Vulnerabilities-Help-Shape-Security-Features-And-Mitigations-In-Android.pdf

Appendix

Google

Calculating VBMeta Digest from Factory Image

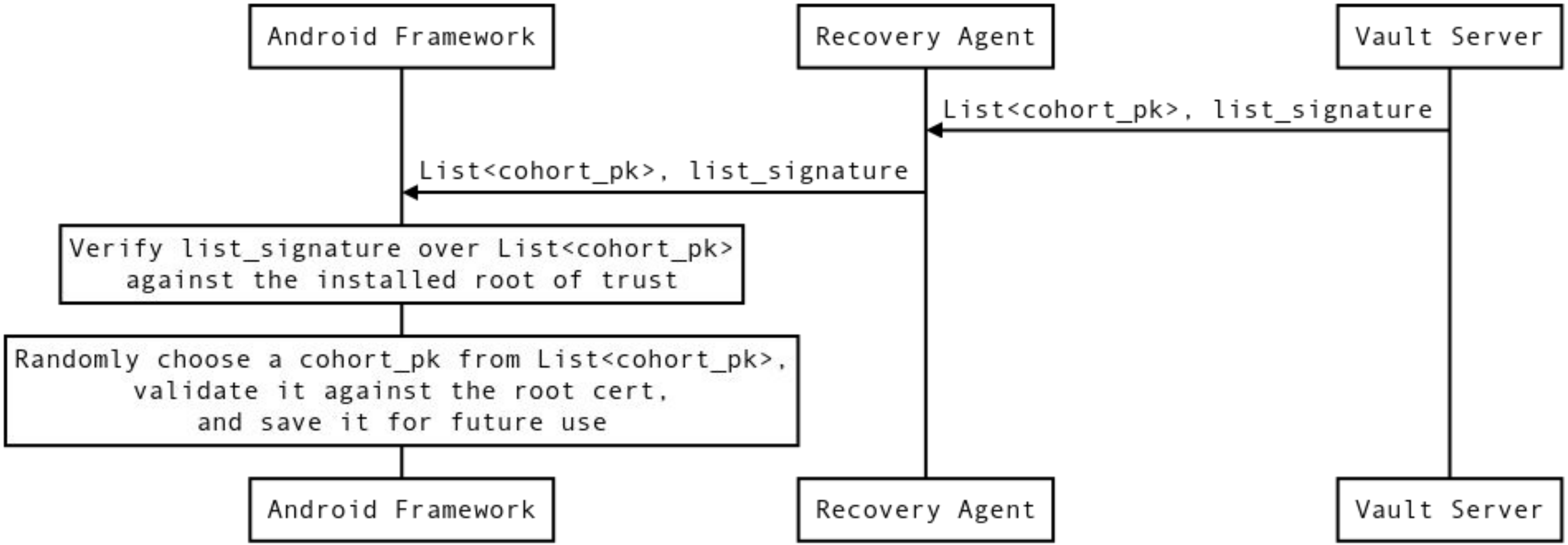
- Build avbtool from AVB 2.0 AOSP.
- Download and unzip factory image for Pixel 3.
- Validate that VBMeta structures match up with referenced partitions.
    - `avbtool verify_image --image vbmeta.img --follow_chain_partitions`
- Calculate VBmeta Digest
    - `avbtool calculate_vbmeta_digest --image vbmeta.img`

Attesting VBMeta Digest

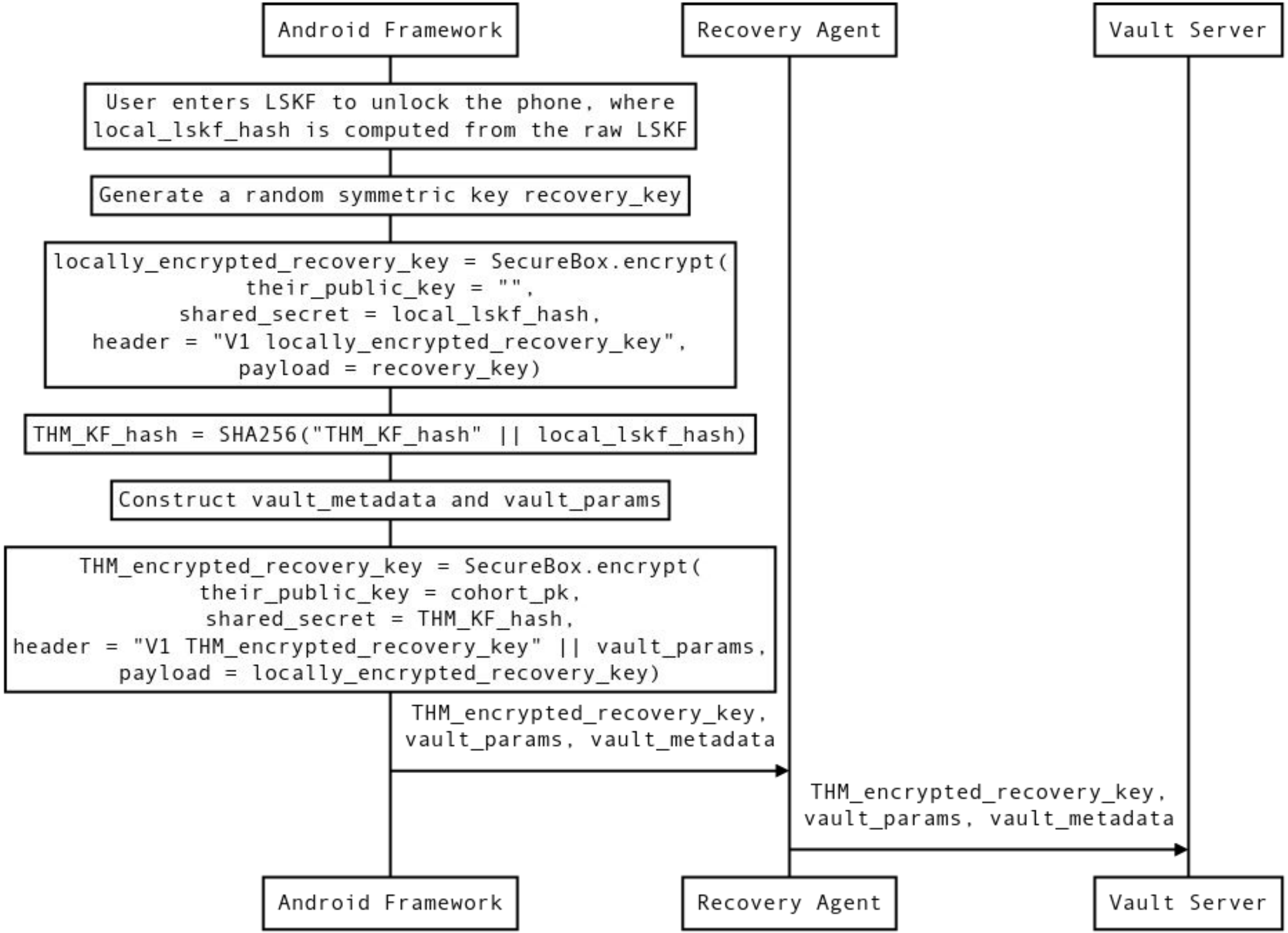
- DevicePolicyManager.generateKeyPair() to get AttestedKeyPair
- AttestedKeyPair.getAttestationRecord() to get Key Attestation Cert Chain
- Validate the chain up to the Google root certificate
- Extract extension OID 1.3.6.1.4.1.11129.2.1.17 from leaf certificate
- RootOfTrust sequence contains verifiedBootHash field with VBMeta Digest

```
RootOfTrust ::= SEQUENCE {
    verifiedBootKey  OCTET_STRING,
    deviceLocked  BOOLEAN,
    verifiedBootState  VerifiedBootState,
    verifiedBootHash OCTET_STRING,
}
```

Encrypted backup key protocol (Details)

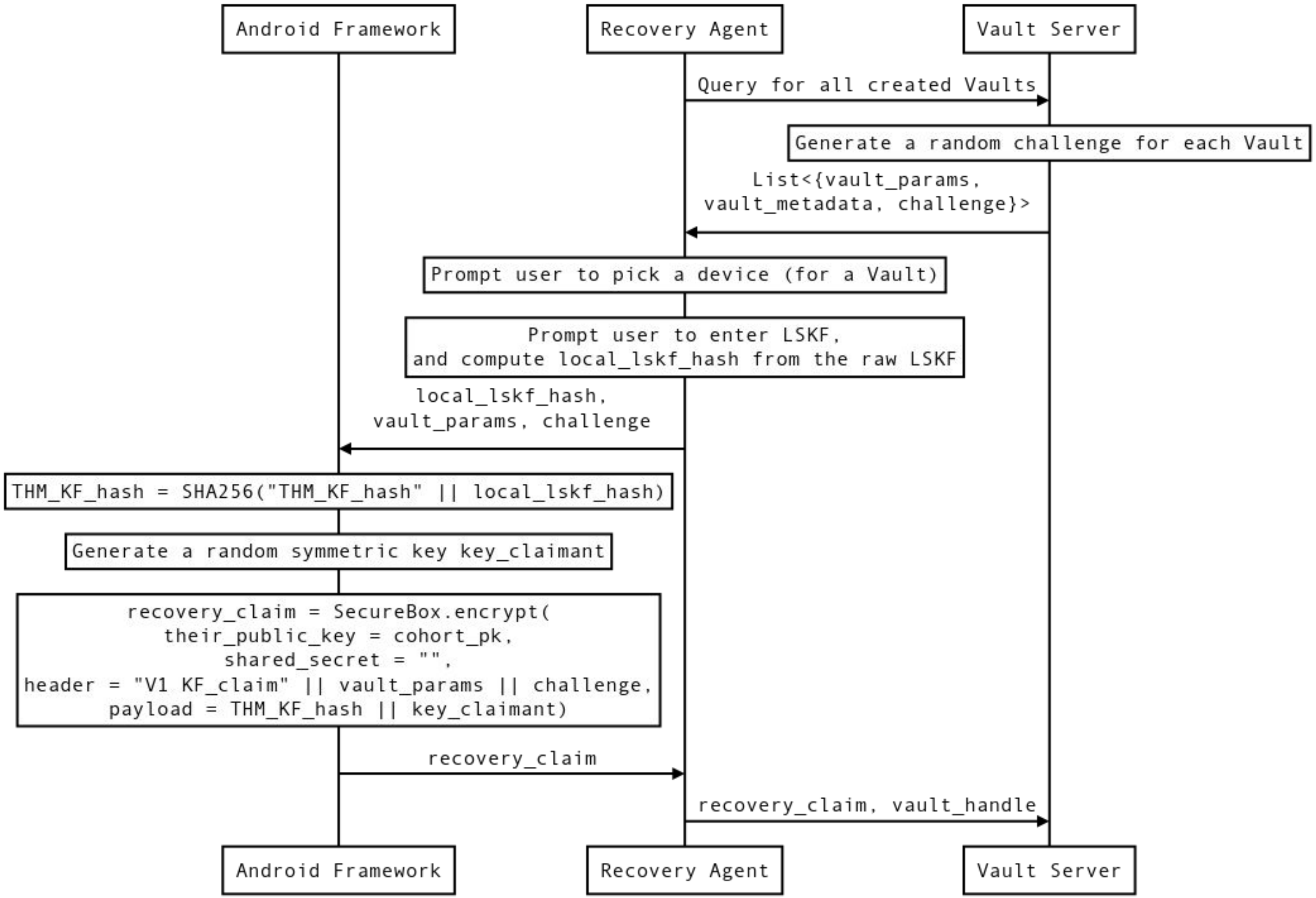


https://developer.android.com/about/versions/pie/security/ckv-whitepaper
https://security.googleblog.com/2018/10/google-and-android-have-your-back-by.html
Cohort public keys: https://www.gstatic.com/cryptauthvault/v0/cert.xml

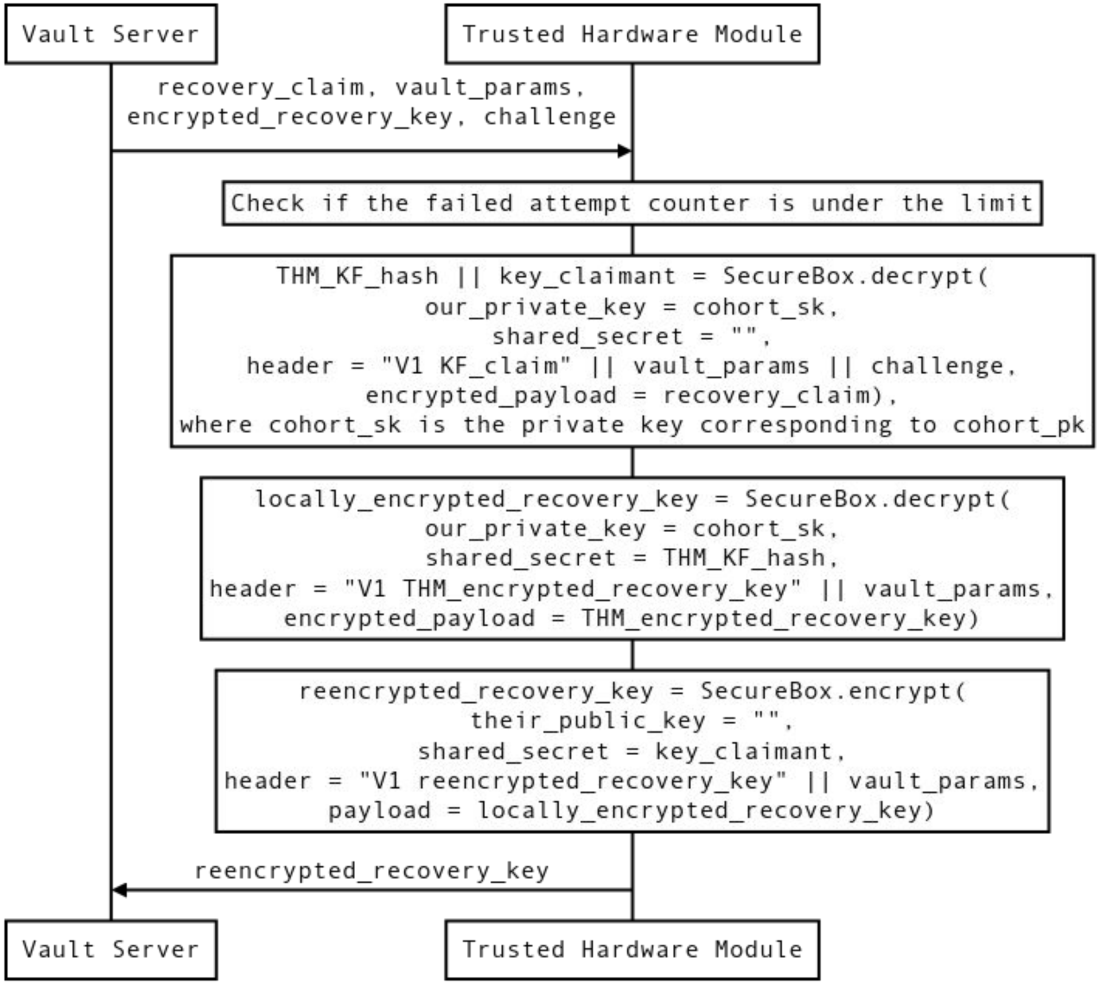


Android Framework
Recovery Agent
Vault Server
User enters LSKF to unlock the phone, where local_lskf_hash is computed from the raw LSKF
Generate a random symmetric key recovery_key
locally_encrypted_recovery_key = SecureBox.encrypt(
their_public_key = "",
shared_secret = local_lskf_hash,
header = "V1 locally_encrypted_recovery_key",
payload = recovery_key)
THM_KF_hash = SHA256("THM_KF_hash" || local_lskf_hash)
Construct vault_metadata and vault_params
THM_encrypted_recovery_key = SecureBox.encrypt(
their_public_key = cohort_pk,
shared_secret = THM_KF_hash,
header = "V1 THM_encrypted_recovery_key" || vault_params,
payload = locally_encrypted_recovery_key)
THM_encrypted_recovery_key,
vault_params, vault_metadata
THM_encrypted_recovery_key,
vault_params, vault_metadata
Android Framework
Recovery Agent
Vault Server

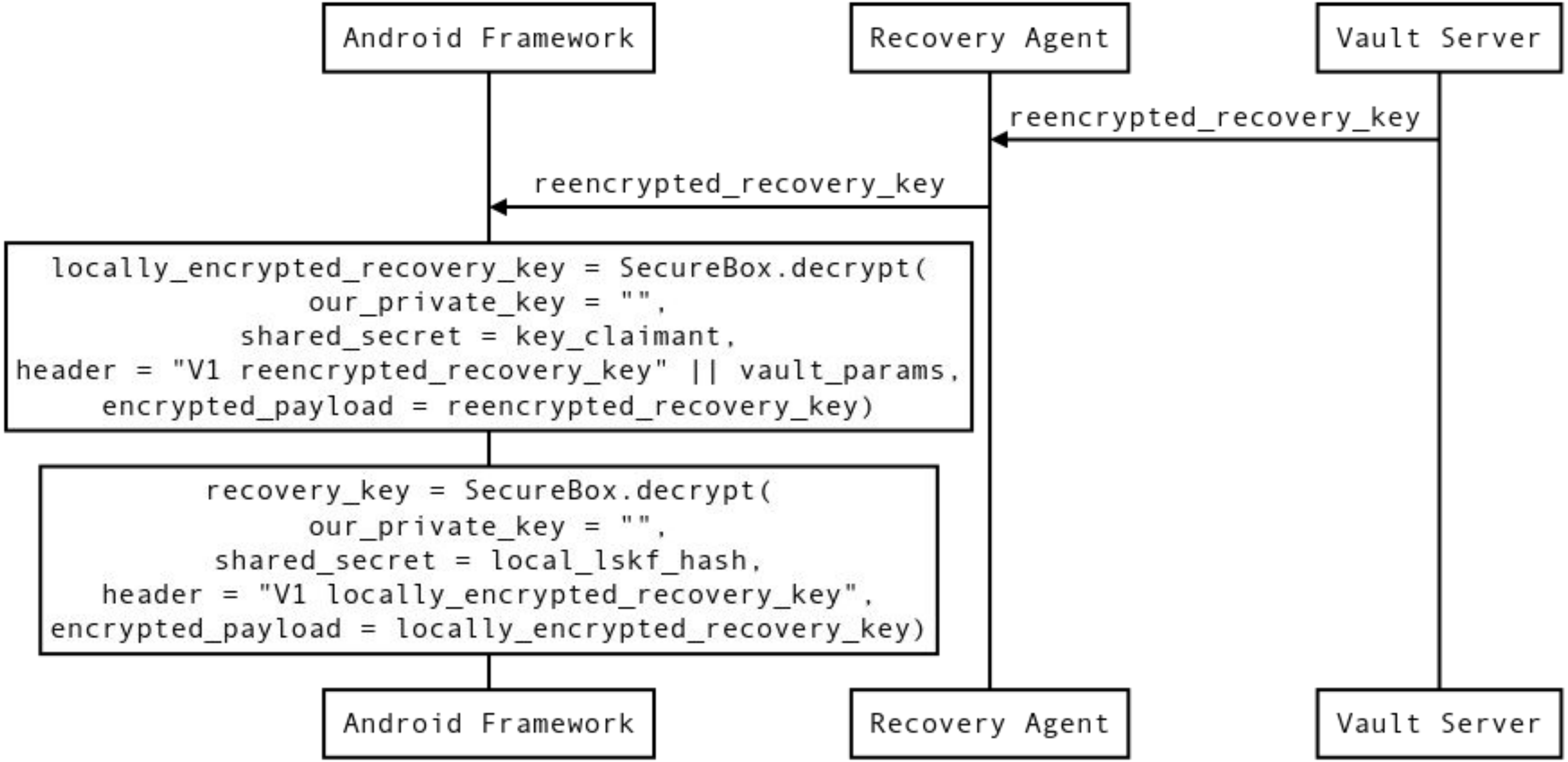
Google


Android Framework
Recovery Agent
Vault Server
Query for all created Vaults
Generate a random challenge for each Vault
List<{vault_params,
vault_metadata, challenge}>
Prompt user to pick a device (for a Vault)
Prompt user to enter LSKF,
and compute local_lskf_hash from the raw LSKF
local_lskf_hash,
vault_params, challenge
THM_KF_hash = SHA256("THM_KF_hash" || local_lskf_hash)
Generate a random symmetric key key_claimant
recovery_claim = SecureBox.encrypt(
their_public_key = cohort_pk,
shared_secret = "",
header = "V1 KF_claim" || vault_params || challenge,
payload = THM_KF_hash || key_claimant)
recovery_claim
recovery_claim, vault_handle
Android Framework
Recovery Agent
Vault Server

Google



Vault Server
Trusted Hardware Module
recovery_claim, vault_params,
encrypted_recovery_key, challenge
Check if the failed attempt counter is under the limit
THM_KF_hash || key_claimant = SecureBox.decrypt(
our_private_key = cohort_sk,
shared_secret = "",
header = "V1 KF_claim" || vault_params || challenge,
encrypted_payload = recovery_claim),
where cohort_sk is the private key corresponding to cohort_pk
locally_encrypted_recovery_key = SecureBox.decrypt(
our_private_key = cohort_sk,
shared_secret = THM_KF_hash,
header = "V1 THM_encrypted_recovery_key" || vault_params,
encrypted_payload = THM_encrypted_recovery_key)
reencrypted_recovery_key = SecureBox.encrypt(
their_public_key = "",
shared_secret = key_claimant,
header = "V1 reencrypted_recovery_key" || vault_params,
payload = locally_encrypted_recovery_key)
reencrypted_recovery_key
Vault Server
Trusted Hardware Module


Android Framework
Recovery Agent
Vault Server
reencrypted_recovery_key
reencrypted_recovery_key
locally_encrypted_recovery_key = SecureBox.decrypt(
our_private_key = "",
shared_secret = key_claimant,
header = "V1 reencrypted_recovery_key" || vault_params,
encrypted_payload = reencrypted_recovery_key)
recovery_key = SecureBox.decrypt(
our_private_key = "",
shared_secret = local_lskf_hash,
header = "V1 locally_encrypted_recovery_key",
encrypted_payload = locally_encrypted_recovery_key)
Android Framework
Recovery Agent
Vault Server