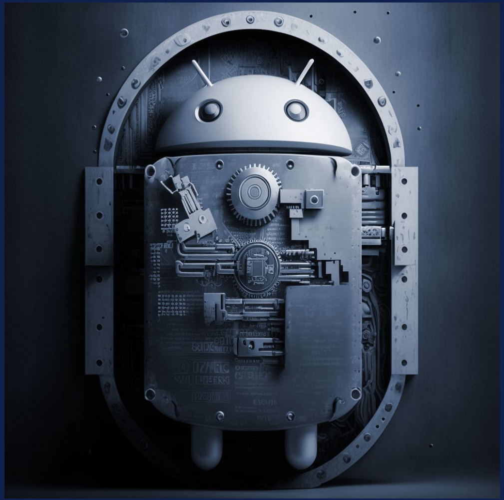
Dissecting the Modern Android Data Encryption Scheme

Maxime Rossi Bellom
Damiano Melotti



Quarkslab

Who we are

- @DamianoMelotti
- Security researcher @ Quarkslab
- Interested in low-level mobile security and fuzzing

- @max_r_b
- Security researcher and R&D leader @ Quarkslab
- Working on mobile and embedded software security

The trigger

> Hey! My device fell into water and the main SoC is dead. However the Titan M[1,2] chip seems to be alive and well, do you think you would be able to help me recover my data on the phone?

[1]: 2021: A Titan M Odyssey (Maxime Rossi Bellom, Philippe Teuwen, Damiano Melotti)
[2]: Attack on Titan M, Reloaded: Vulnerability Research on a Modern Security Chip (Damiano Melotti, Maxime Rossi Bellom)

The trigger

- Our answer: no, the main SoC is still essential for disk encryption/decryption
  - … but up to what extent?
- Objective of this research: find out exactly
- Offensive approach:
  - What would a forensic analyst do?
  - Assuming infinite vulnerabilities, what can you do to get the secrets out?
  - Do you still need to bruteforce credentials?

Data Encryption at Rest 101

- Idea: no sensitive plaintext files in storage
  - Attackers must not find files in clear on disk
- Threat model: full physical access to powered-off device
- Data is automatically encrypted when written and automatically decrypted when read
- How?
  - Android: Full-Disk Encryption and File-Based Encryption (required from Android 10)
  - Underneath: dm-crypt for FDE, fscrypt for FBE

File-Based Encryption at Rest 101

- Relies on `fscrypt`, implemented in the Linux kernel
  - It supports Ext4, F2FS, and UBIFS
- Operates at the filesystem level
  - Allows files encrypted with different keys or unencrypted in a file system
- A master key is provided for directory tree
- Then derived per file keys (for regular file, directory, and symbolic link)
- Metadata are not encrypted by `fscrypt`

Android File-Based Encryption

- Each file has its own key
- Direct Boot and multi-user support
- Two encryption levels:
    - Credential Encrypted (CE), available only after authentication
    - Device Encrypted (DE), available also during boot
- In short, 2 “main” keys
    - DE key, for data decrypted at boot
    - CE key, available after authentication, protecting user data
- DE key is automatically decrypted using HW-backed keys

Android File-Based Encryption

```
a22x:/ # ls /data/data | head -n 20
+BWqxAAAAAQGIO5OZ57bZxMl6oTCNKCs
+geIWCAAAAgIsCJB+mpPqIQYOH0FrnojC1KJ8e0lvGZWJYXWFTc0WD
+lE39AAAAwnVineHXItKqcE1Glo9+EinbUaa3wvp,fXEjaJ3r4BiC
+ostbBAAAAwZ2g592ei8GG2DMfc4y6H94jxkEfoRzUDdlQZnOYZKqA5VCUgi89sf2JN8yCBFraC
,0wF+BAAAAgQtSCvHd5rRmVC2lVxEHt1Eo50M9kma1oe+vkWT176K8dxofVp5RcmnLv0xC7WMLJ
,WGCADAAAAg66o3+mZ7f009fBNp8zQSdWBqRJIwPUZHafQiTu7khxB
,eGnGDAAAAw+ZAptd14KRyth5ncJmJkYAZBTBW7DoUNpMamRGjO5MA
,vu29CAAAAgKApb3amvoChi0pYILwr5xxvUtfOTpZ2h6Cr0wG4CR5D
0MQ5GCAAAAQAtXNLN524L3GwuGAek+rVelNjgE5mwqljisOkydZa2FKJlVD6ezJJGkcjcRTTD7B
0QcmpBAAAAwMxohHqP+AT3ktRtIAJk9,bu2g04xwjLzf,vgN71QQ2B
0WZ9mBAAAAA5KuJUTYZ61eUrgnVJAlOJnZDm3b7JybYYPw8xhLrf0D
11ppkCAAAAAI4M8ENP6k0t3rA9kIN9bepZ0FdpiYDp6bQ5Cj2IU2NB
13nD7DAAAAw,NoobtAOXesI0kFqFC4MIwoKYAfdBQrGTm8rfbbdsNC
1K0haDAAAAAIbCCdZY7LE6W4+DAXnAiv,PEhu4CiUL6ofn9ZuL6buC
1V6luAAAAAwmrNINeM84y83,LYzeNEkdCcACNxlAhJ+sI7VzbV51yuebjw9MOPTrjRi9cv391kD
1fMeDAAAAAgPnPYDGuOWWC8uWiojo+nhhnqWk+x0ZerDfrWY3ZVIbB
1hGHtCAAAAwfxP3KkXNUYQOSWoBzqZcsbu2g04xwjLzf,vgN71QQ2B
2d3fjDAAAAgf7ilkMftxkJiD0JbRx9,dtgO4Rk9L1P5CCl7JuqqewNpAl07TQqOKJh2yXzcj9,8JfbjIHwnpEmj7FQ0ixXBP
2v,UXBAAAAQloHyVKO8uify8onfmrQXJawy1Dqwq6kc2g2BKrOH48D
2wjJhBAAAAgQ0MvGF3NqTpssmh6XgAWw1jHW986vSwQMXIPQQz6ghD
```

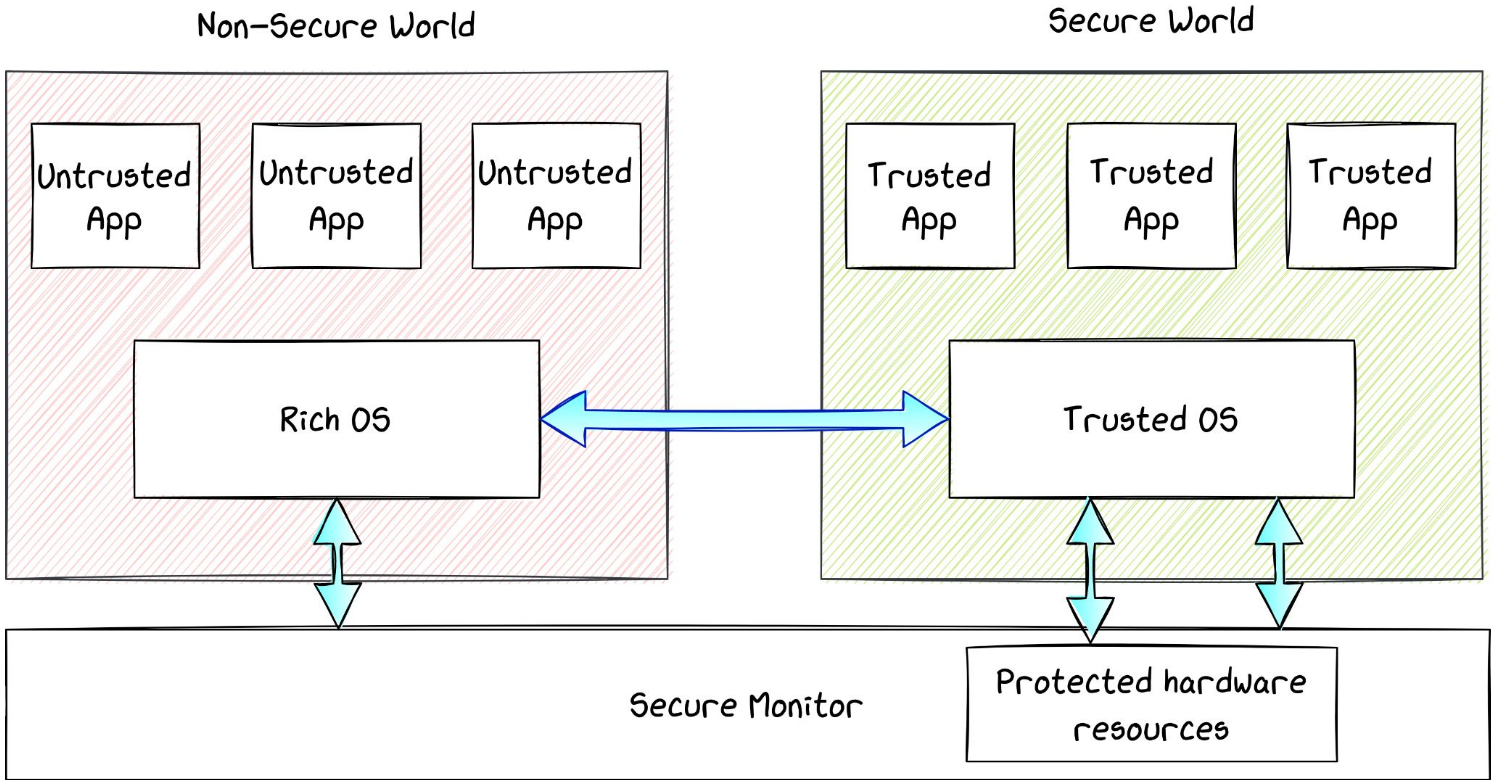
FBE key derivation

- We focus only on the CE key
- Complex derivation steps
  - Start from DE files owned by privileged users

```
a22x:/ # ls -l /data/system_de/0/spblob/
total 32
-rw------- 1 system system    58 2022-06-29 21:59 0000000000000000.handle
-rw------- 1 system system    72 2022-06-29 21:59 921e9ab09afd8d9d.metrics
-rw------- 1 system system    93 2022-06-29 21:59 921e9ab09afd8d9d.pwd
-rw------- 1 system system 16384 2022-06-29 21:59 921e9ab09afd8d9d.secdis
-rw------- 1 system system   186 2022-06-29 21:59 921e9ab09afd8d9d.spblob
```

- User credentials are used in the process
  - No matter how many bugs an attacker has, bruteforcing remains necessary!

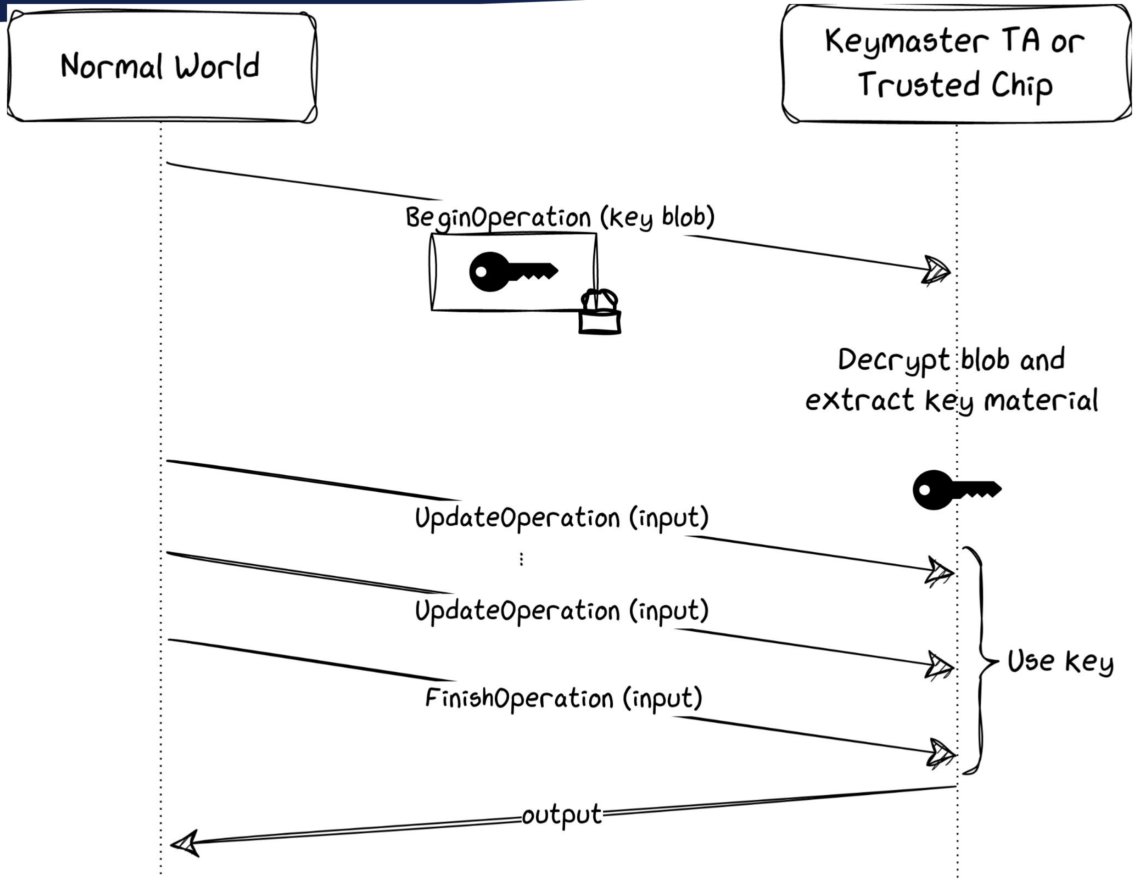
ARM TrustZone

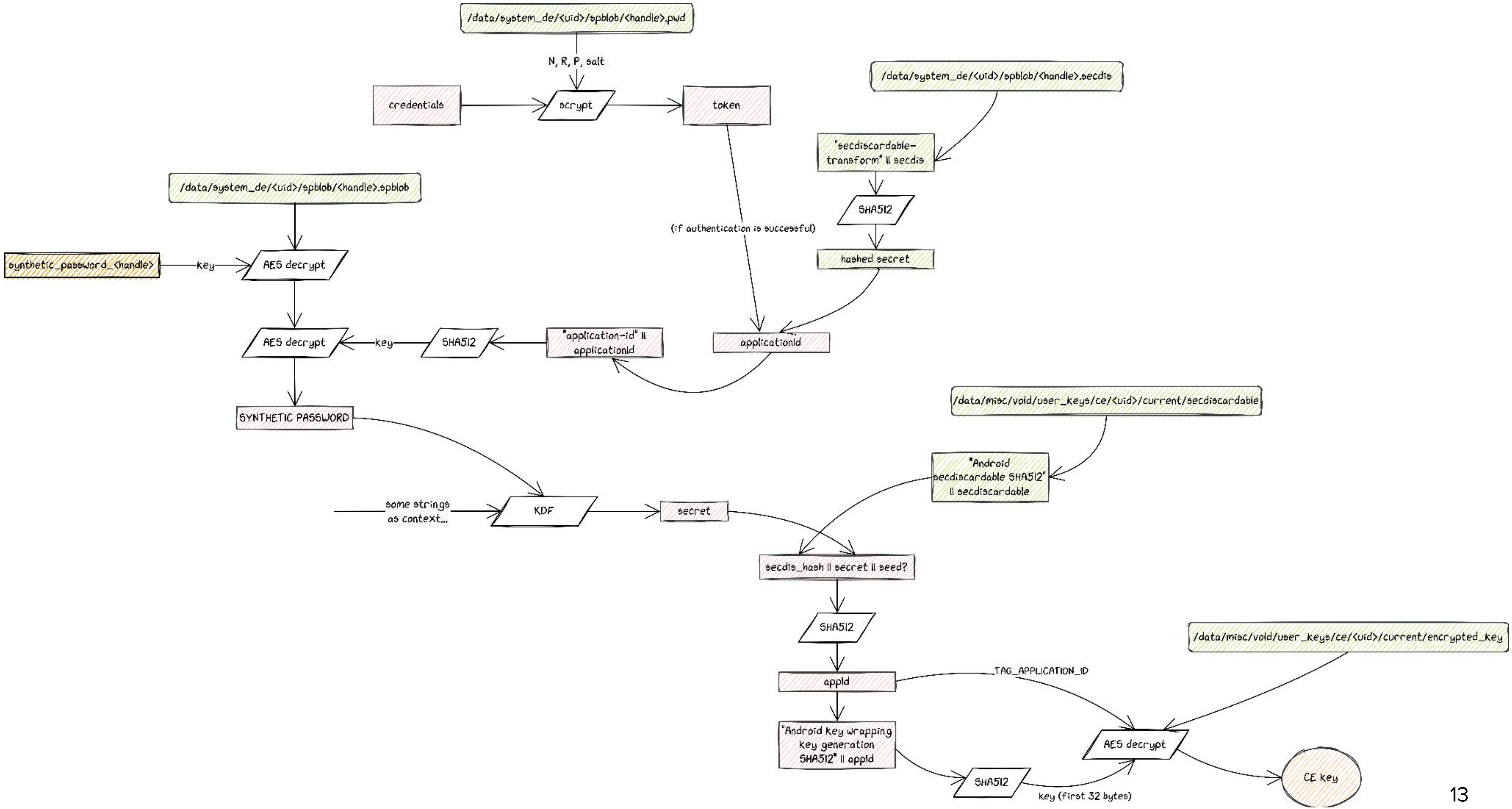


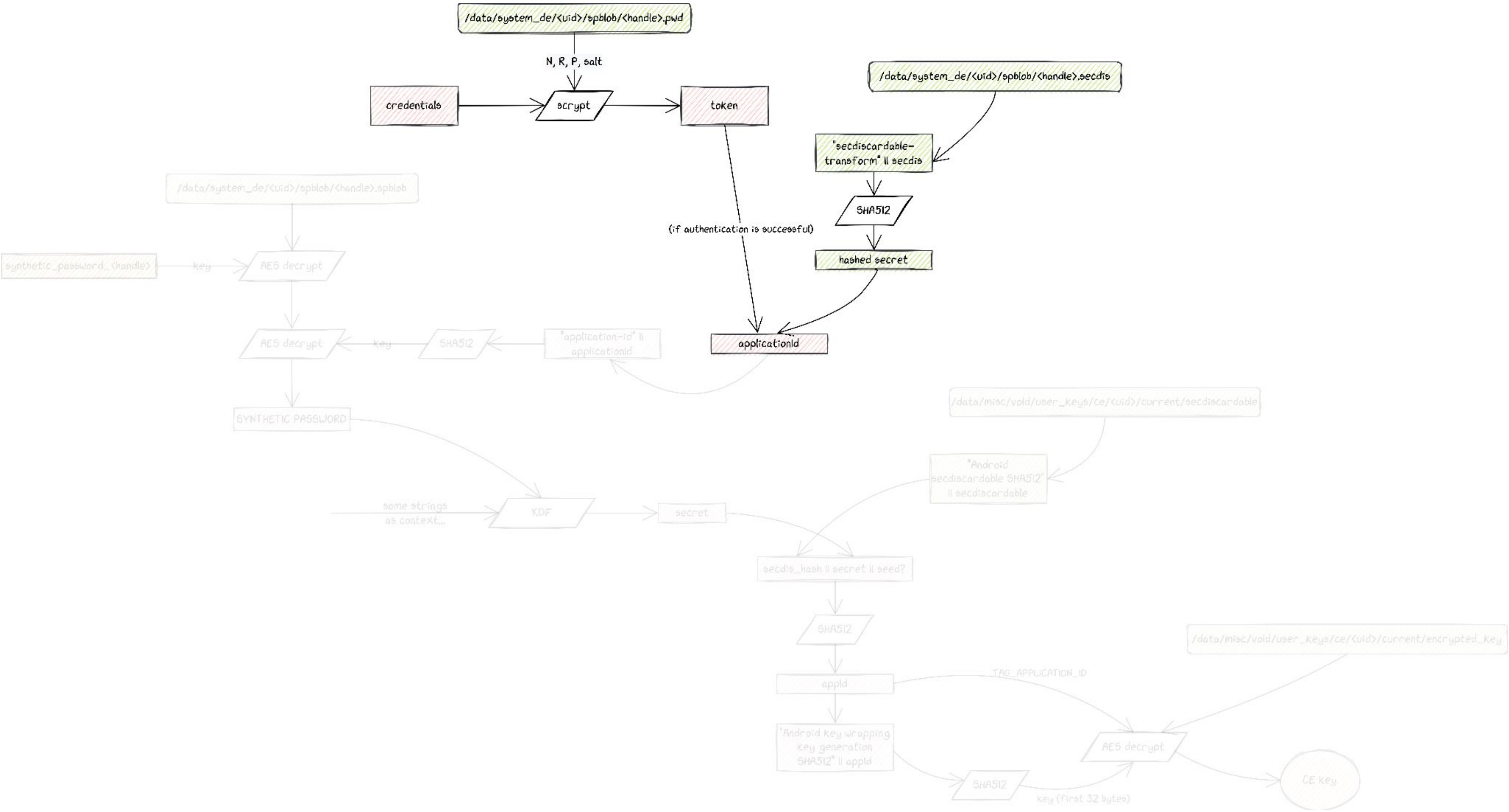
Android Keystore system

- Key storage and crypto services
- Keys are stored as *key blobs*
- Three protection levels:
  - Software only
  - TEE (default)
  - Hardware-backed (StrongBox)
- Raw key should never leave protected environment

Android Keystore system




/data/system_de/<uid>/spblob/<handle>.pwd
N, R, P, salt
credentials
scrypt
token
/data/system_de/<uid>/spblob/<handle>.secdis
"secdiscardable-transform" ll secdis
SHA512
hashed secret
(if authentication is successful)
/data/system_de/<uid>/spblob/<handle>.spblob
synthetic_password_<handle>
key
AES decrypt
AES decrypt
key
SHA512
"application-id" ll applicationId
applicationId
SYNTHETIC PASSWORD
/data/misc/vold/user_keys/ce/<uid>/current/secdiscardable
"Android secdiscardable SHA512" ll secdiscardable
some strings as context...
KDF
secret
secdis_hash ll secret ll seed?
SHA512
/data/misc/vold/user_keys/ce/<uid>/current/encrypted_key
appId
TAG_APPLICATION_ID
"Android key wrapping key generation SHA512" ll appId
AES decrypt
SHA512
key (first 32 bytes)
CE key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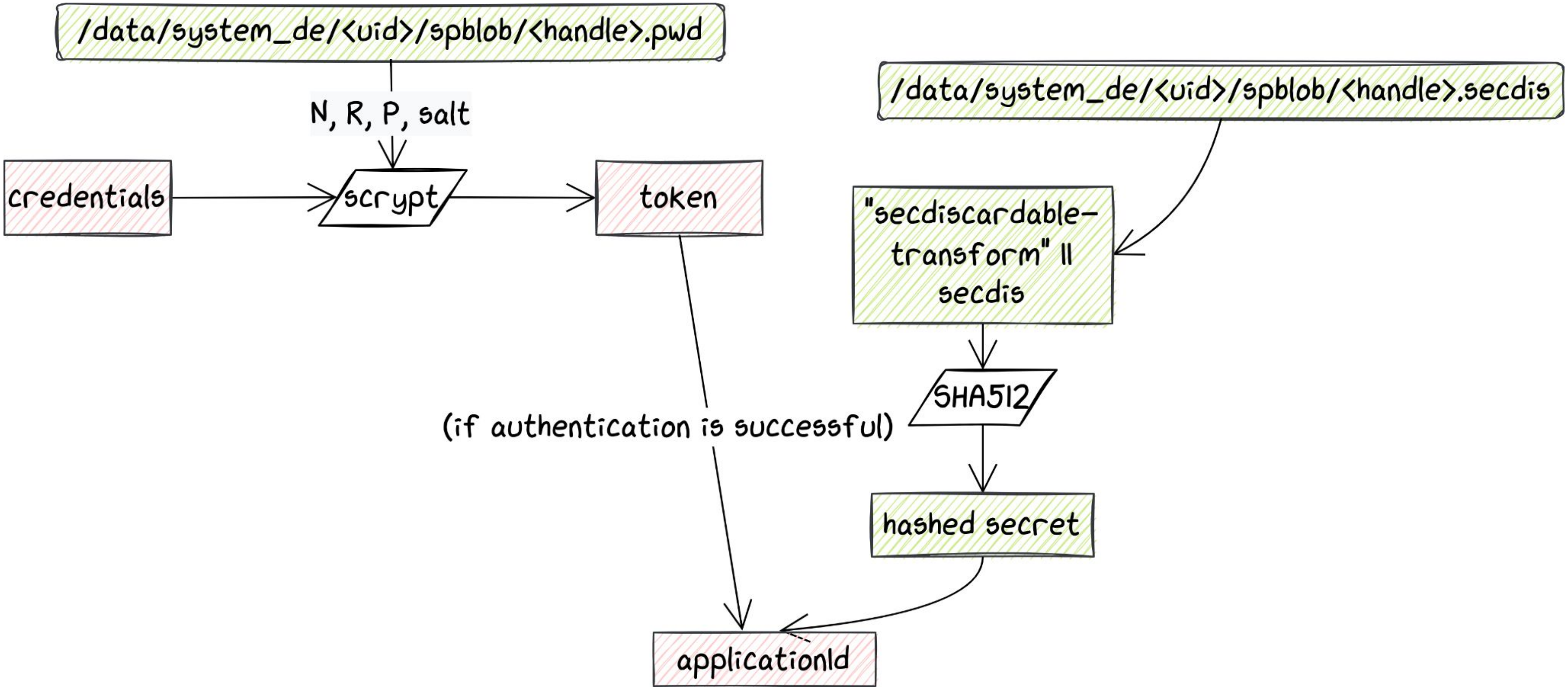
key (first 32 bytes)
CE key

Credentials, scrypt, secdis

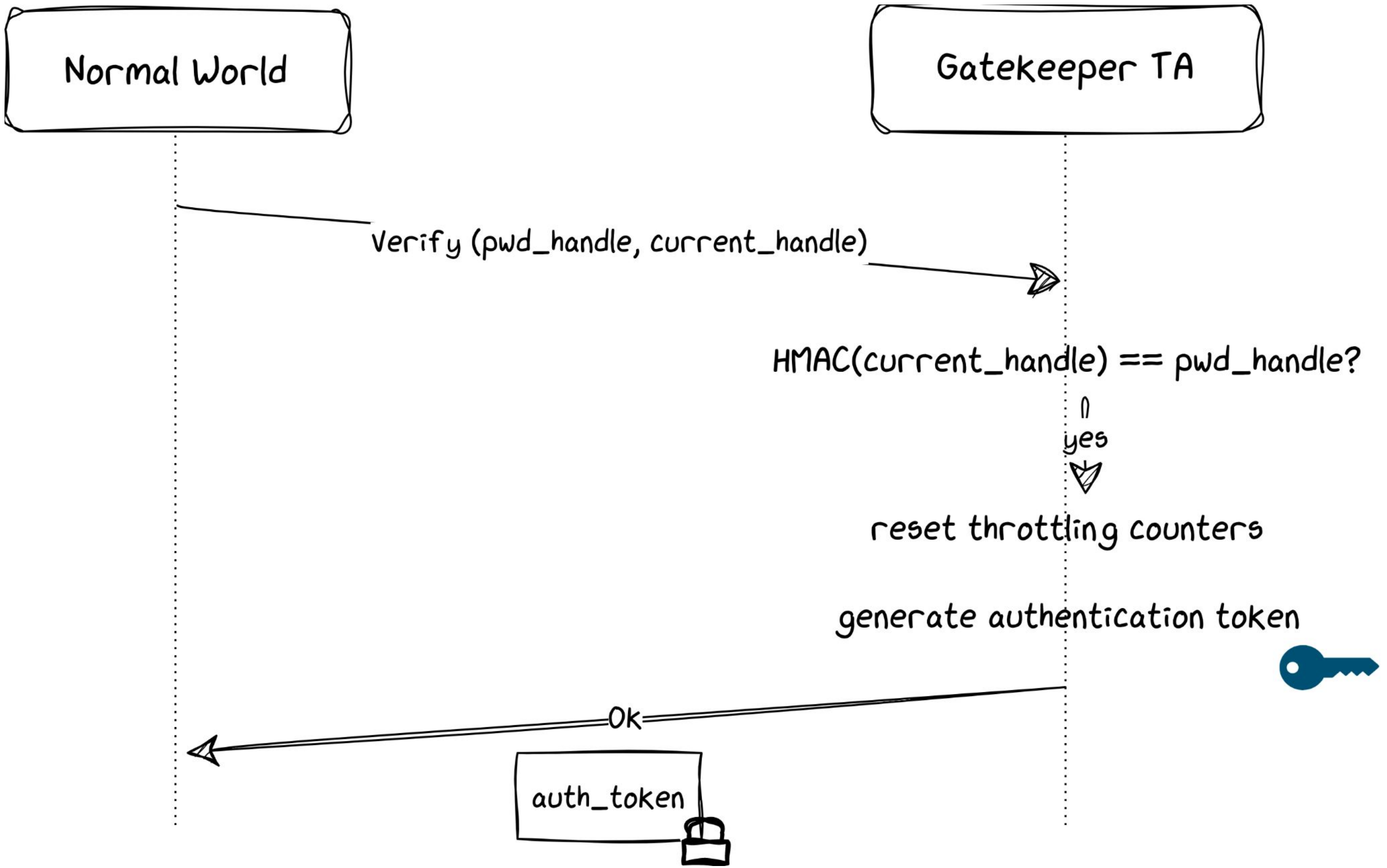


Authentication with Gatekeeper

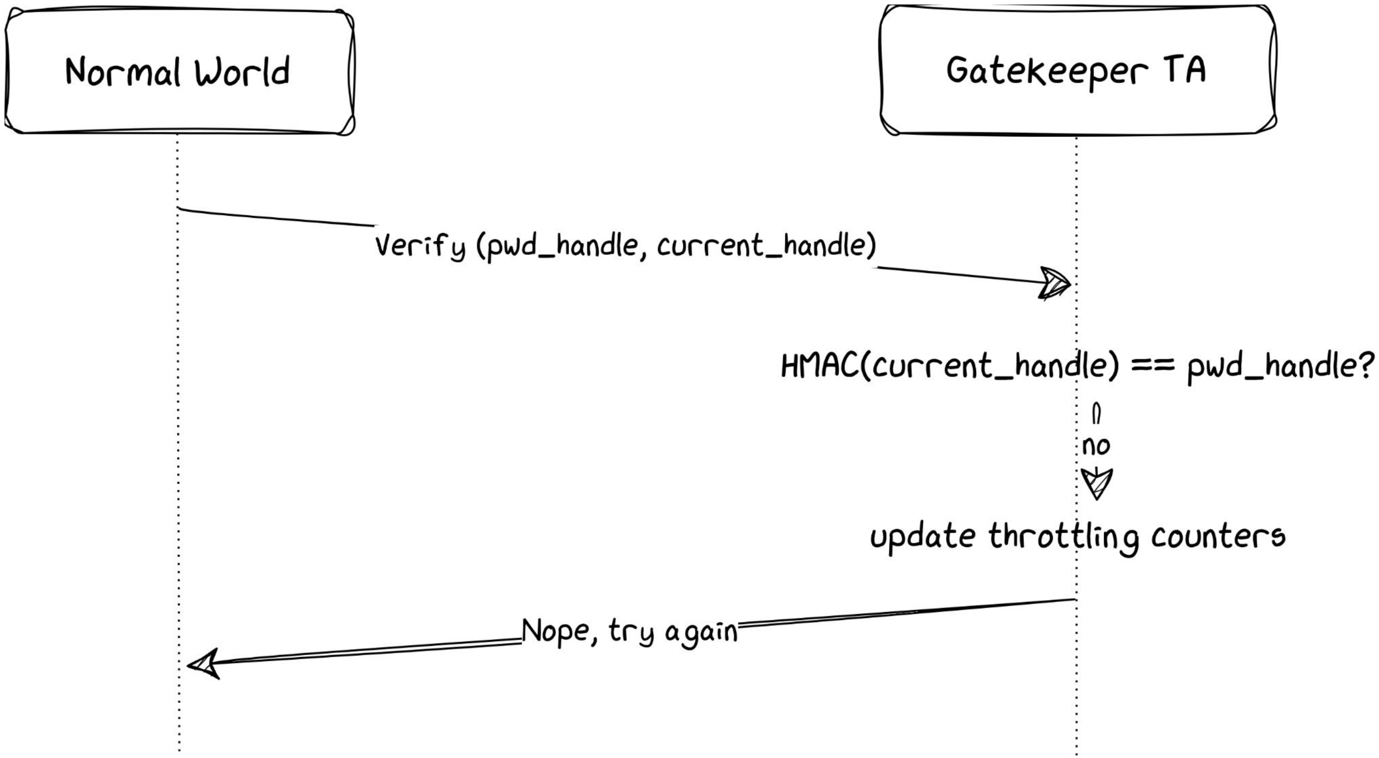
- The Gatekeeper TA verifies credentials from the TEE
- `/data/system_de/<uid>/spblob/<handle>.pwd`
  - scrypt parameters
  - *password handle*, i.e. `HMAC(SHA512("user-gk-authentication" || scrypt(credentials, params))`
- If successful, Gatekeeper returns an *authentication token*
  - Signed token to be used to prove successful authentication
  - Needed by Keymaster to use authentication-bound keys
  - Standard format, designed not to allow replay attacks[3]
- Gatekeeper implements throttling to prevent bruteforcing

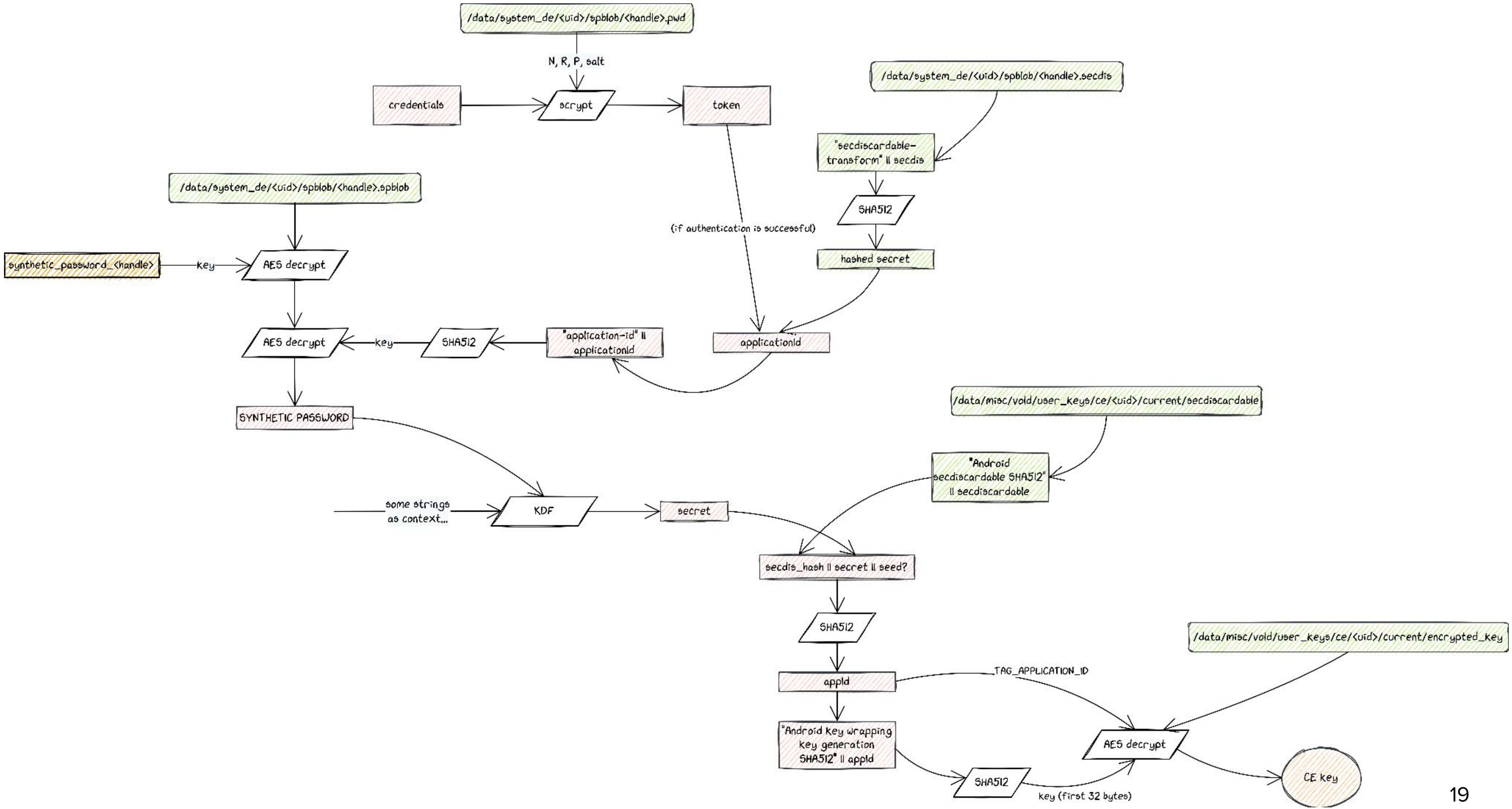
[3]: https://android.googlesource.com/platform/hardware/libhardware/+/master/include/hardware/hw_auth_token.h

Successful authentication



Failed authentication

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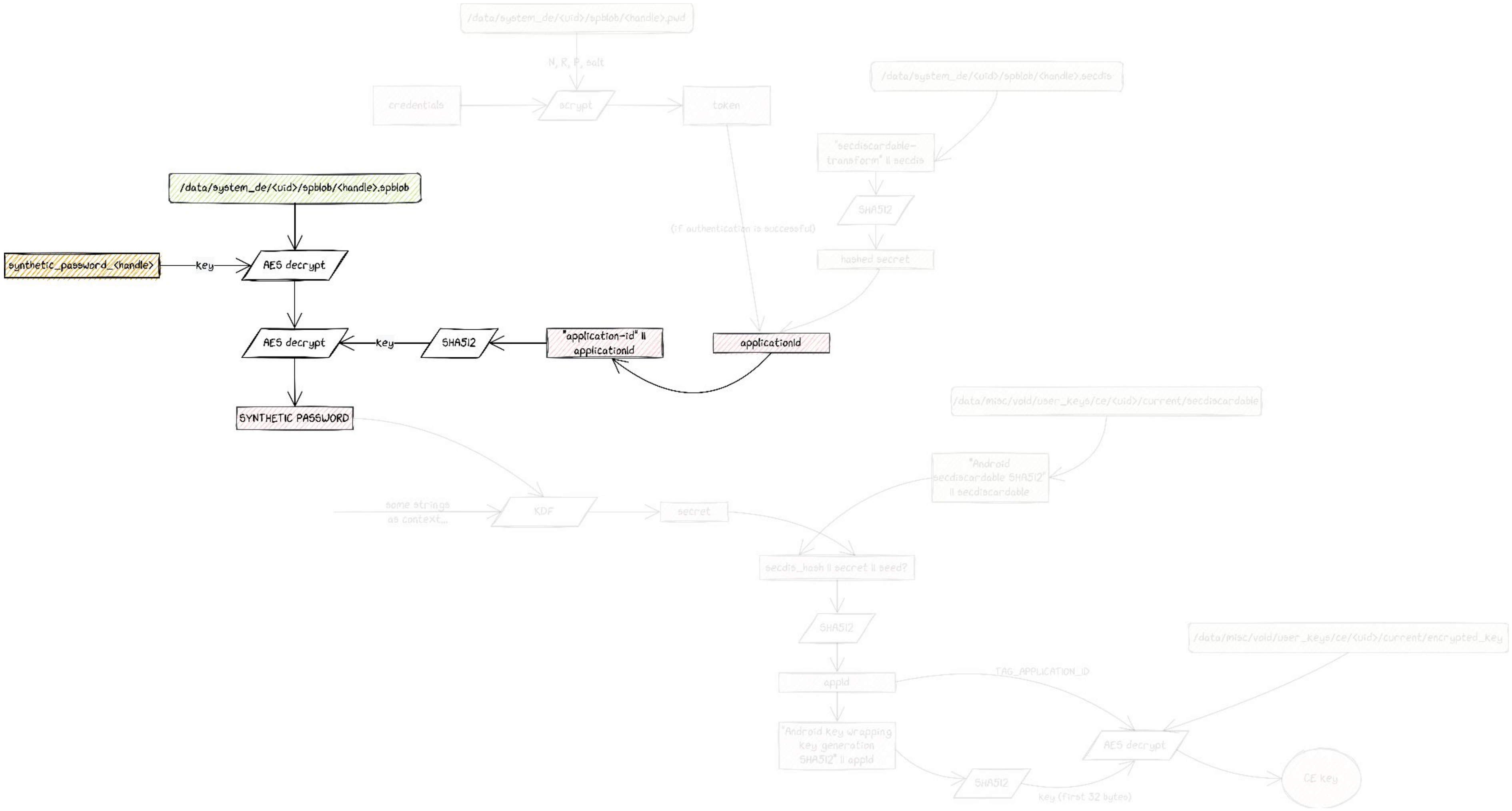

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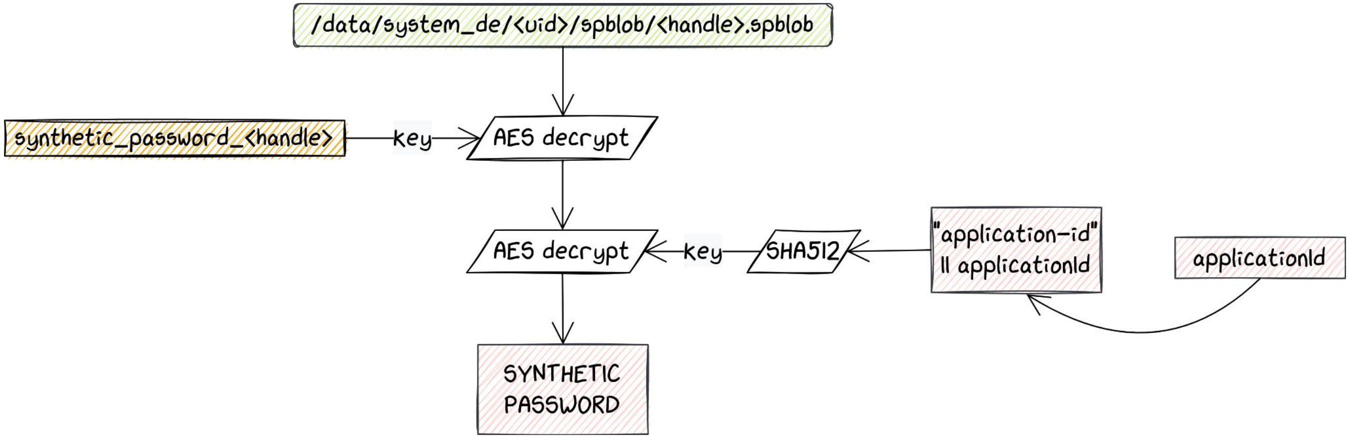
appId
/data/misc/vold/user_keys/ce/<uid>/current/encrypted_key
TAG_APPLICATION_ID
"Android key wrapping key generation SHA512" ll appId
AES decrypt
SHA512
key (first 32 bytes)
CE key

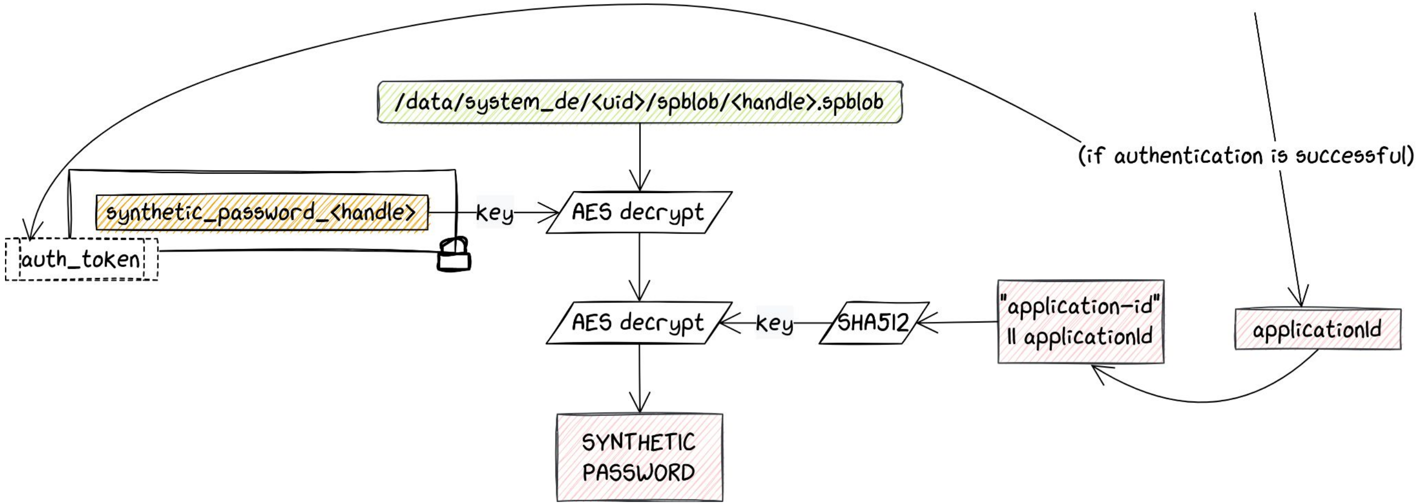
Synthetic Password

- Problem: credentials shouldn’t be linked to the CE key
  - What if the user changes them?
- Solution: Synthetic Password
  - Key blob stored in `/data/system_de/<uid>/spblob/<handle>.spblob`
  - First, decrypted with an authentication-bound, TEE-protected key
  - Then, decrypted with the (hashed) `applicationId`



Attacking SP derivation

- Need to target the TEE
- Two alternatives
  - Keymaster TA (accessing the first AES key)
  - **Gatekeeper TA** (validating credentials and minting auth tokens)



Global strategy

- Our goal
  - Root the device and access all the device encrypted files
  - Patch the Gatekeeper trustlet to accept any credentials
- For that we need
  - Either multiple bugs (code exec, priv esc, etc)
  - Or one critical bug early in the boot process

PoC on Samsung Device

- Samsung A225f and A226b
  - Cheap (~250€)
  - Mediatek SoC MT6769V and MT6833V
  - No security chip
  - Mix of Mediatek and Samsung code
  - Trustzone OS: TEEGRIS
  - Known critical Boot ROM vulnerability

The Boot ROM Known Vulnerability

We use the project MTKClient[4] (by Bjoern Kerler – @viperbjk)

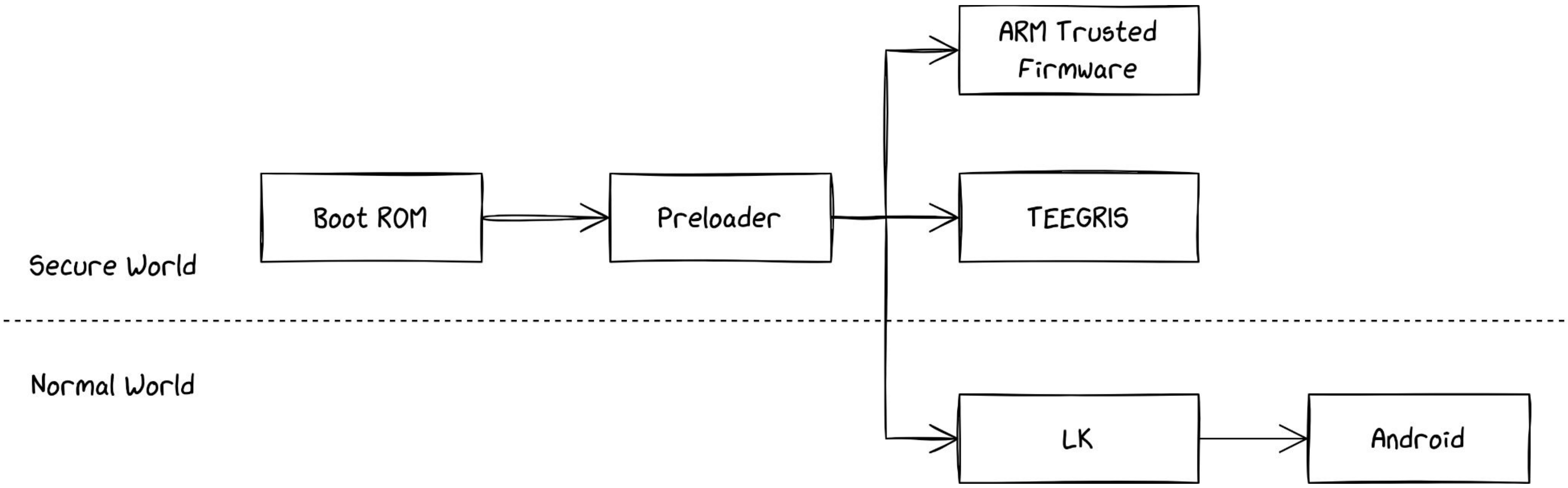
- Exploit boot ROM bugs impacting plenty of Mediatek SoC

In short, we use it to

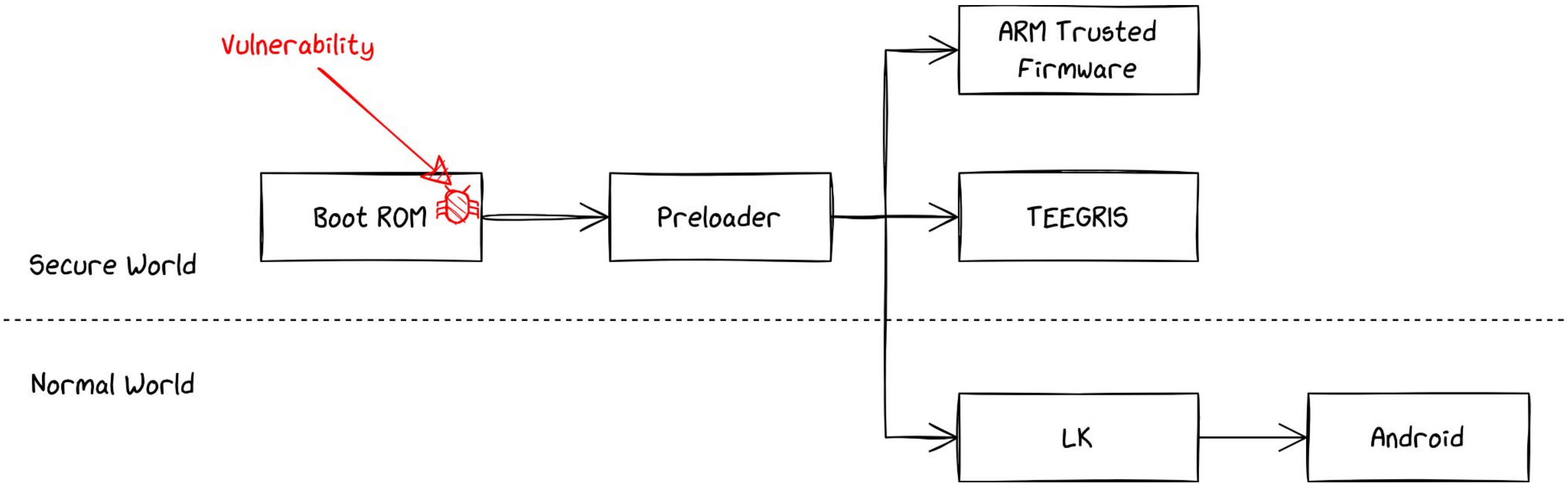
- Read/write all the partitions we need to patch
- Boot a patched preloader (BL2) image
- Bypass the secure boot checks done in boot ROM and preloader
- It just works :)

[4]: https://github.com/bkerler/mtkclient

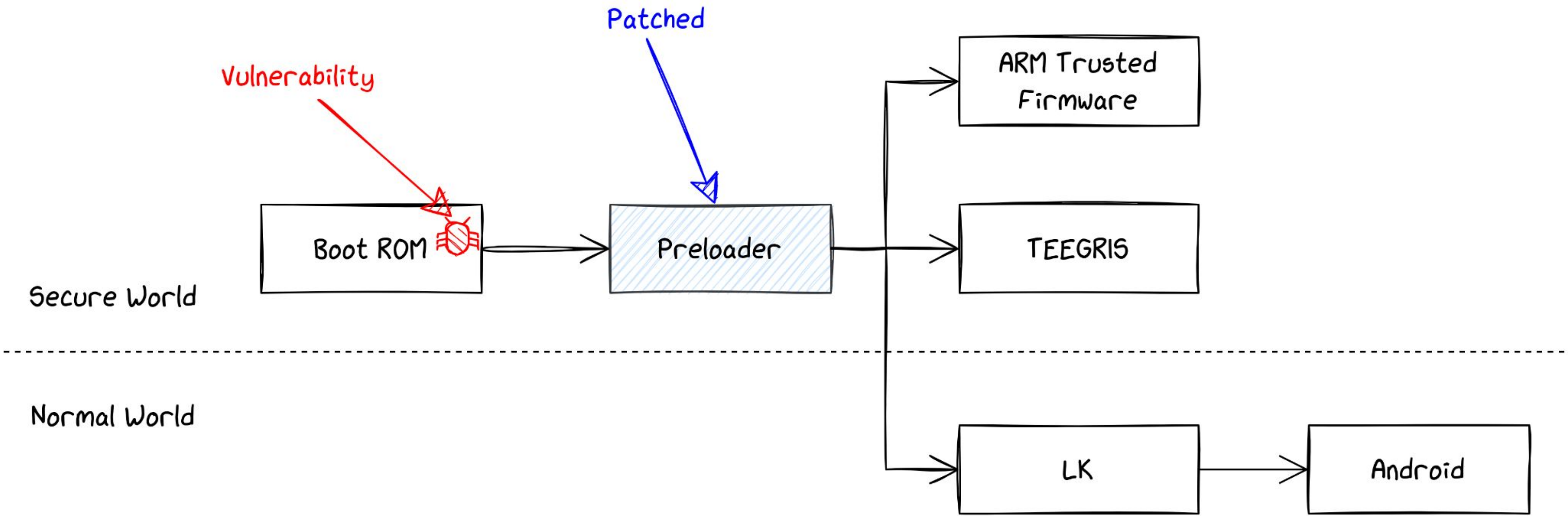
Boot Process



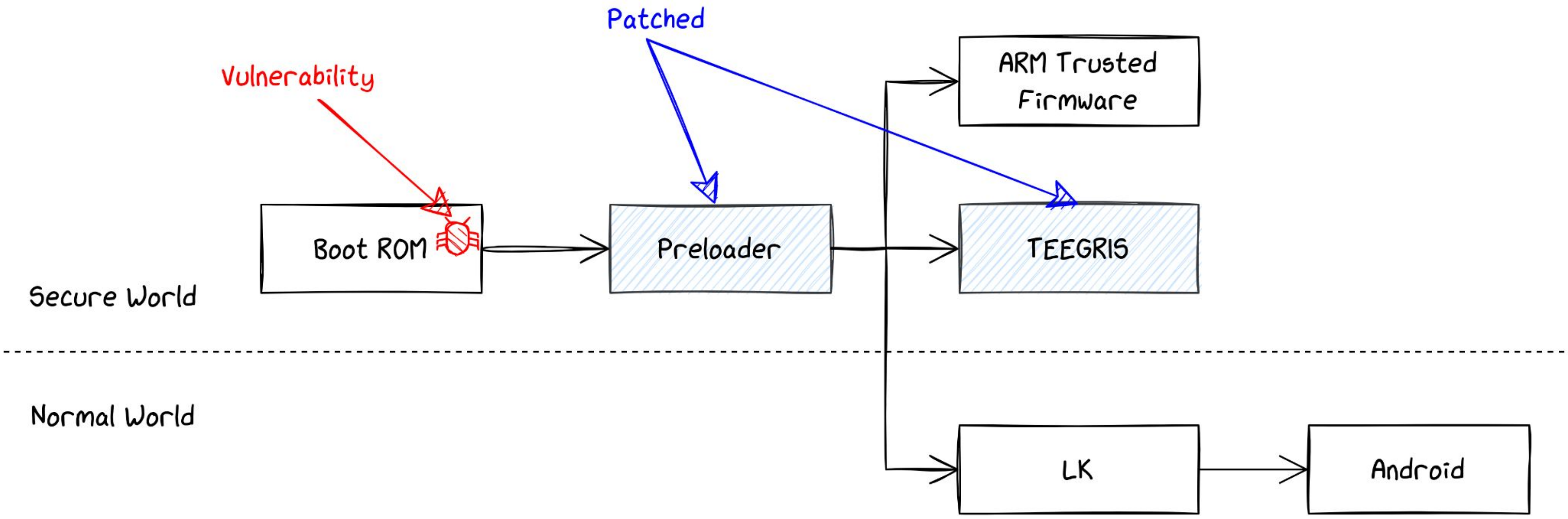
Boot Process



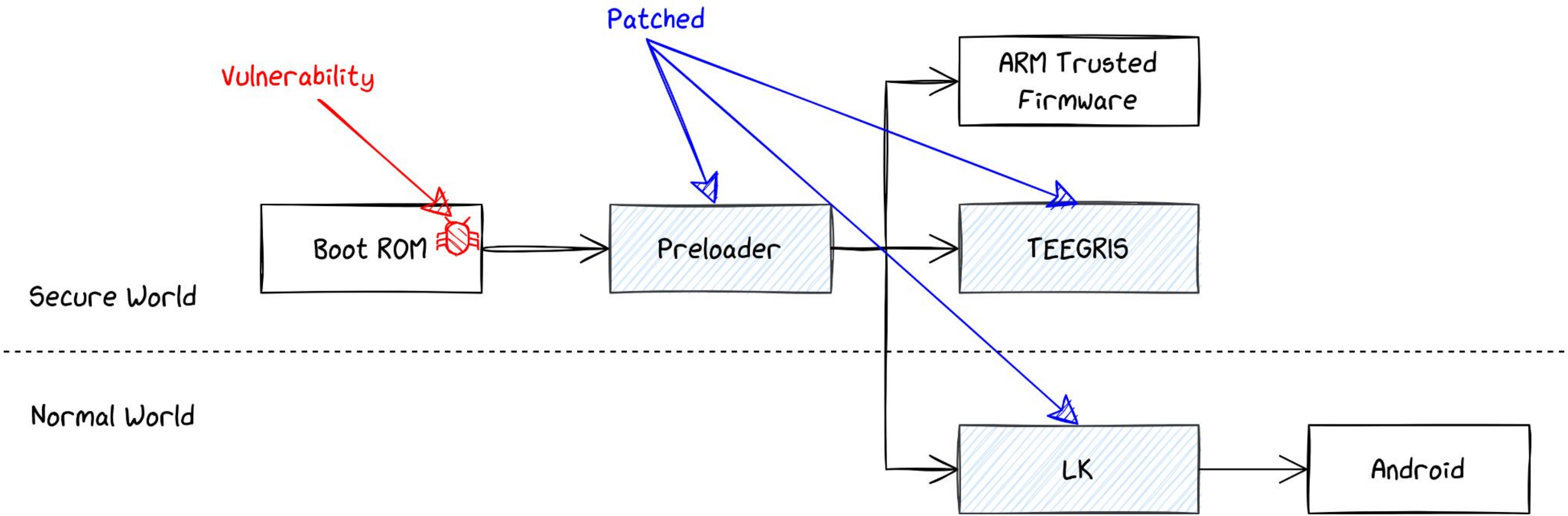
Boot Process



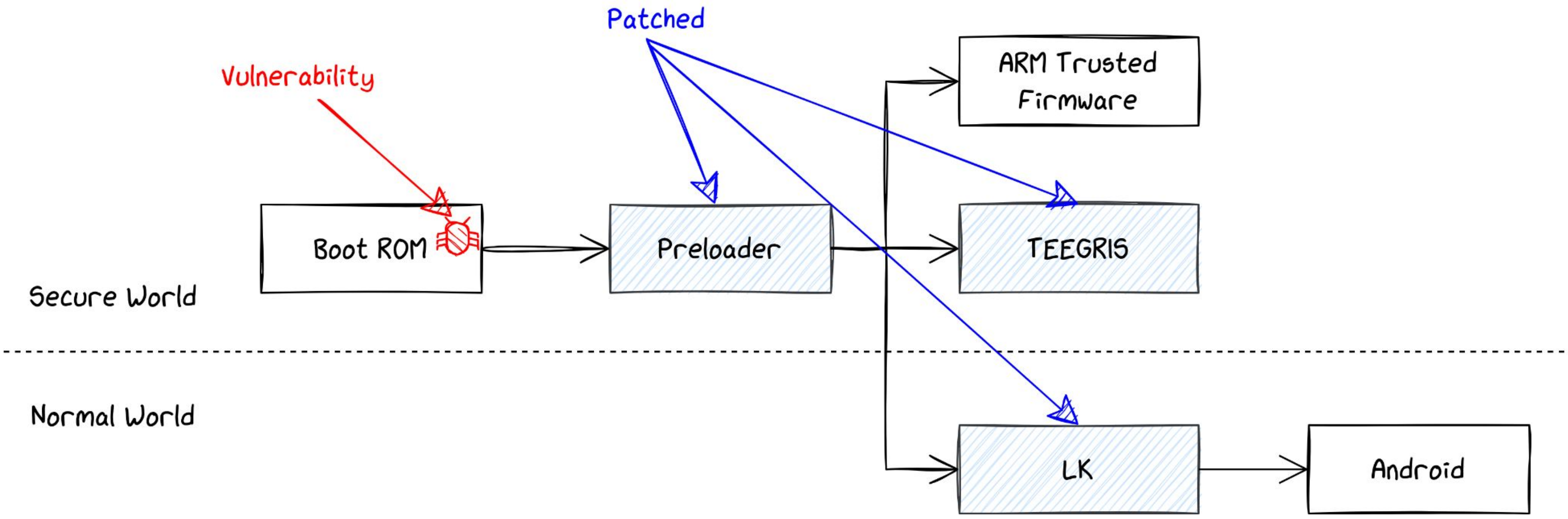
Boot Process



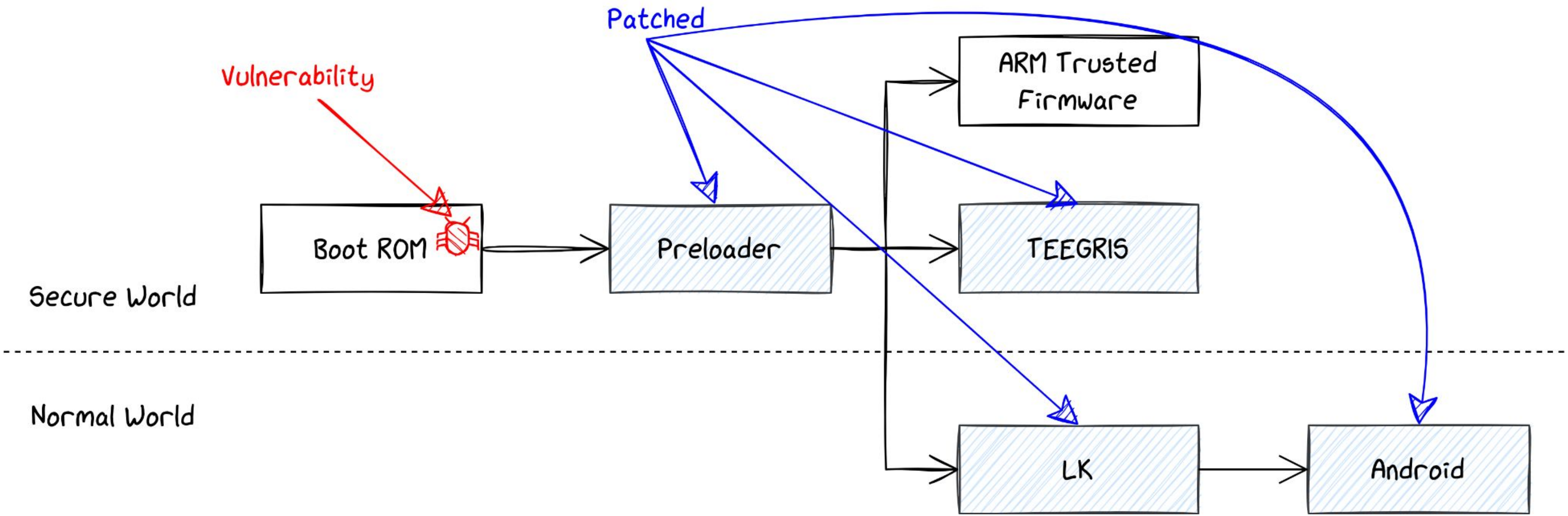
Boot Process



Boot Process

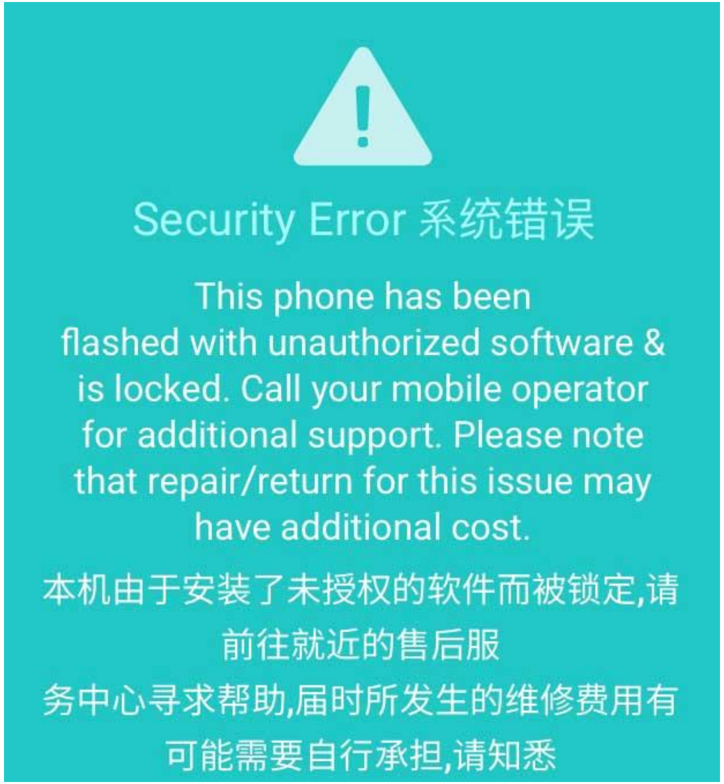


Boot Process



Little Kernel Patching

- Patching strategy: empirical approach
  - Reverse engineering and identify checks
  - Patch, test and repeat
- In the end we patch AVB to launch a modified boot image



Little Kernel Patching

```
iVar1 = do_hash(param_1,param_2,DAT_4c6463e0 - param_2,&hash,0x20);
if (iVar1 == 0) {
  iVar2 = memcmp(&STORED_HASH,&hash,0x20);
  if (iVar2 == 0) {
    print("[%s][oem] img auth pass\n",&s_SBC_030151a8);
    goto LAB_02ff82e0;
  }
  iVar1 = 0x7021;
}
print("[%s][oem] img auth fail (0x%x)\n",&s_SBC_030151a8,iVar1);
```

Little Kernel Patching

```c
iVar1 = do_hash(param_1,param_2,_DAT_4c6463e0 - param_2,&hash,0x20);
if (iVar1 == 0) {
  iVar2 = memcmp(&hash,&hash,0x20);
  if (iVar2 == 0) {
    print("[%s][oem] img auth pass\n",&DAT_030151a8);
    goto LAB_02ff82e0;
  }
  iVar1 = 0x7021;
}
print("[%s][oem] img auth fail (0x%x)\n",&DAT_030151a8,iVar1);
```

Rooting Android

Main partitions used by Android: **boot** and **super**

- Boot contains the kernel and a ramdisk (only used for first boot stage)
- Super is a Dynamic Partition that contains 4 logical partitions
  - system, vendor, product, odm

To root it

- Magisk[5] to patch the boot image
- We made few modifications to su
- Plus other little tricks to patch the super partition

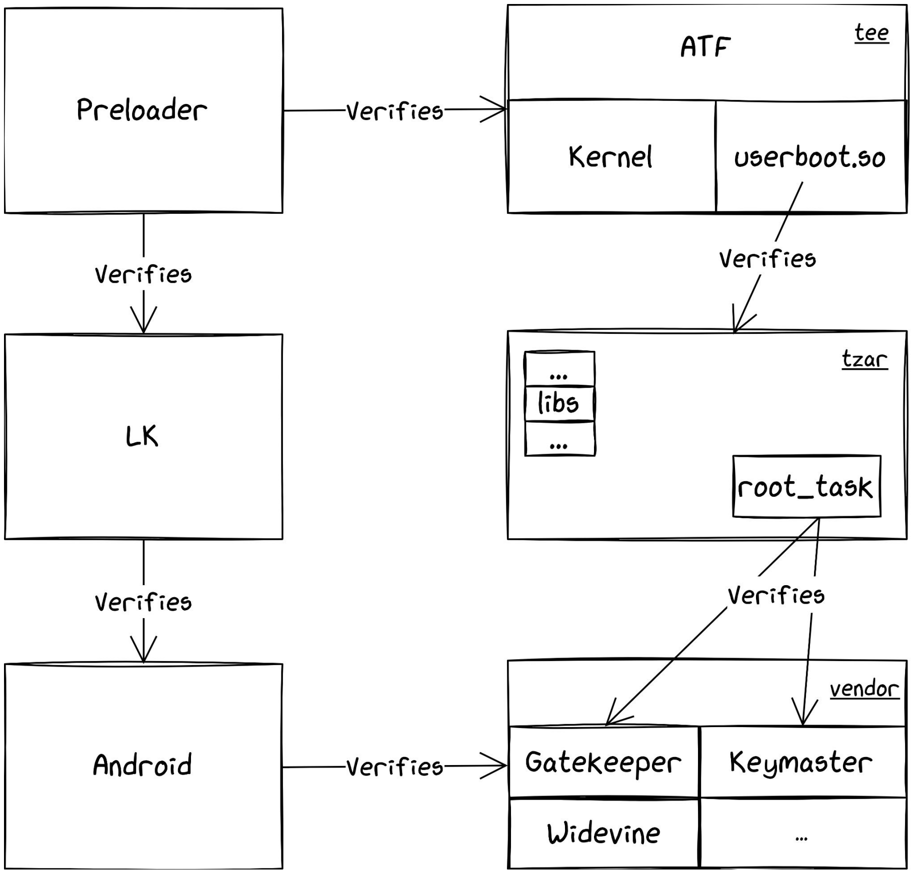
[5]: https://github.com/topjohnwu/Magisk

TEEGRIS

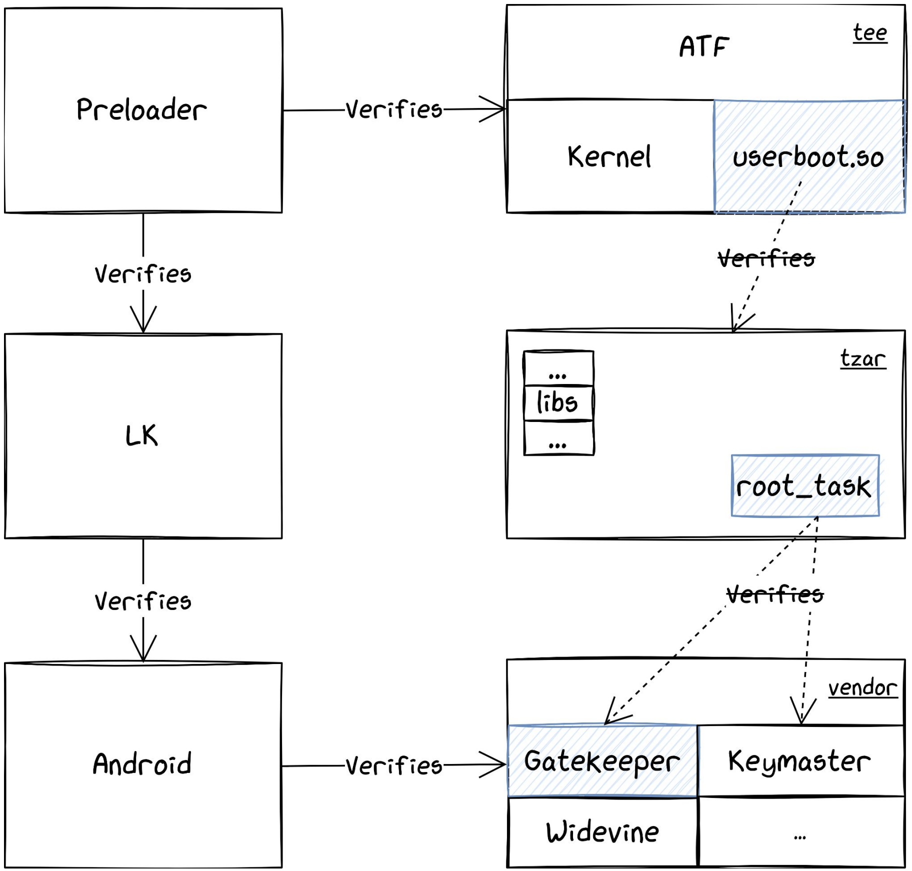
- Trustzone OS designed by Samsung
- For Mediatek and Exynos SoCs
- ROM images:
  - `tee1.img`: ATF, TEEGRIS kernel, `userboot.so`
  - `tzar.img`: TEE root filesystem
  - `super.img`: Android system, Trusted Applications and Drivers
- Excellent references online[6]

[6]: https://www.riscure.com/tee-security-samsung-teegris-part-1/

TEEGRIS Images Verification



Patching TEEGRIS



Reversing Gatekeeper

- TAs come in a slightly modified ELF format
  - 8-bytes header and footer with signature
  - Removing them allows to load a nice ELF in your favourite disassembler
- GlobalPlatform API
  - Standard API for TEEs (memory allocation, crypto operations, etc.)
  - Makes reversing easier
- Trusty reference implementation[7]
  - Suggests what to expect from a TA

[7]: https://source.android.com/docs/security/features/trusty

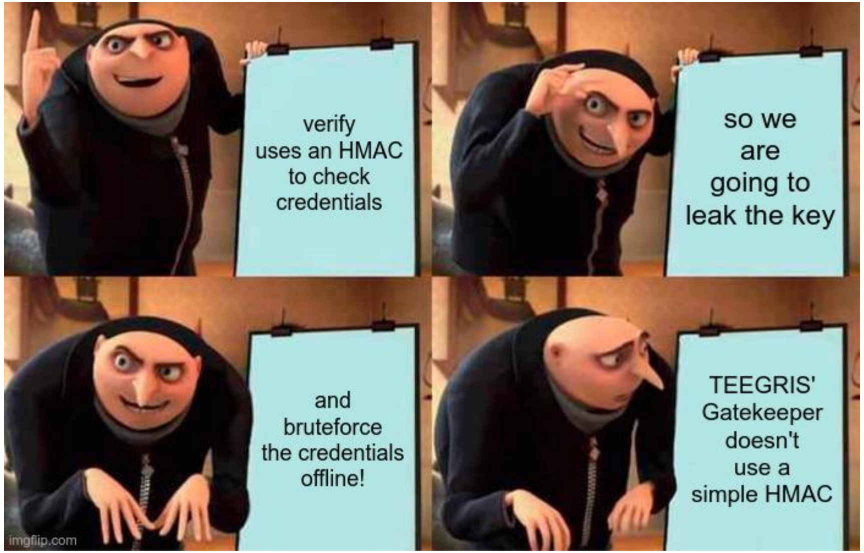
Gatekeeper Reference Implementation

- 2 Gatekeeper commands: `Enroll` and `Verify`
- Verify does two things:
  - `HMAC(pwd_handle) == expected?`
  - If so, create new authentication token
- What if we can leak the key used by HMAC?

1. `pwd = generate new password`
2. `Value = HMAC(pwd_handle)`
3. `Value == expected`

Reversing & patching Gatekeeper

- 2 Gatekeeper commands: `Enroll` and `Verify`
- Verify does two things:
    - `HMAC(pwd_handle) == expected?`
    - If so, create new authentication token



Reversing & patching Gatekeeper

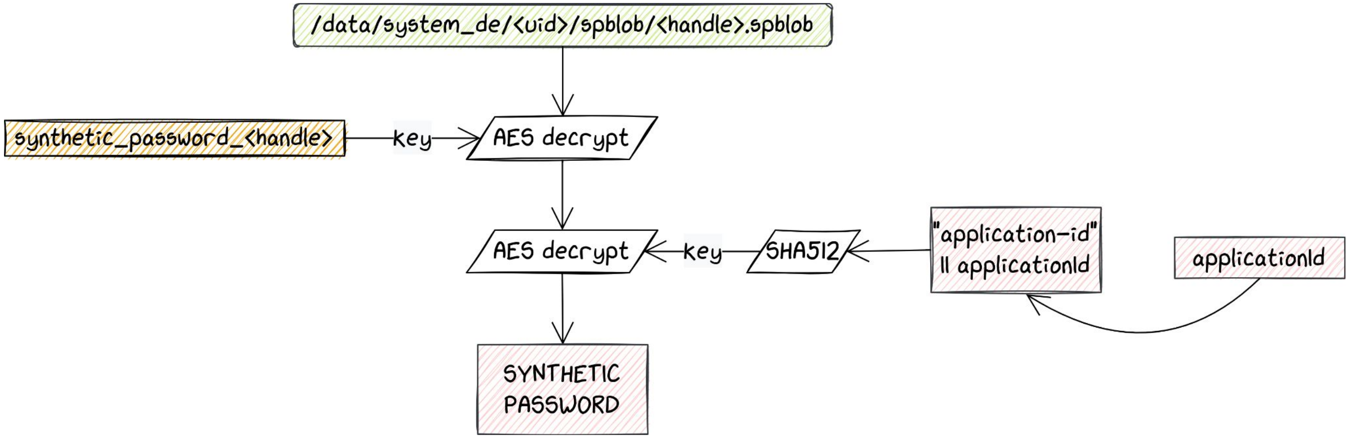
- This Gatekeeper implementation uses a KDF instead of a plain HMAC
  - KDF implemented in a library
  - which calls `/dev/crypto`
  - many steps to leak the key
- Simpler strategy: patch to accept any credentials
- Always return valid auth token to continue the process
  1. ~~`KDF(pwd_handle) == expected?`~~
  2. ~~If so,~~ create new auth_token

Reversing Gatekeeper

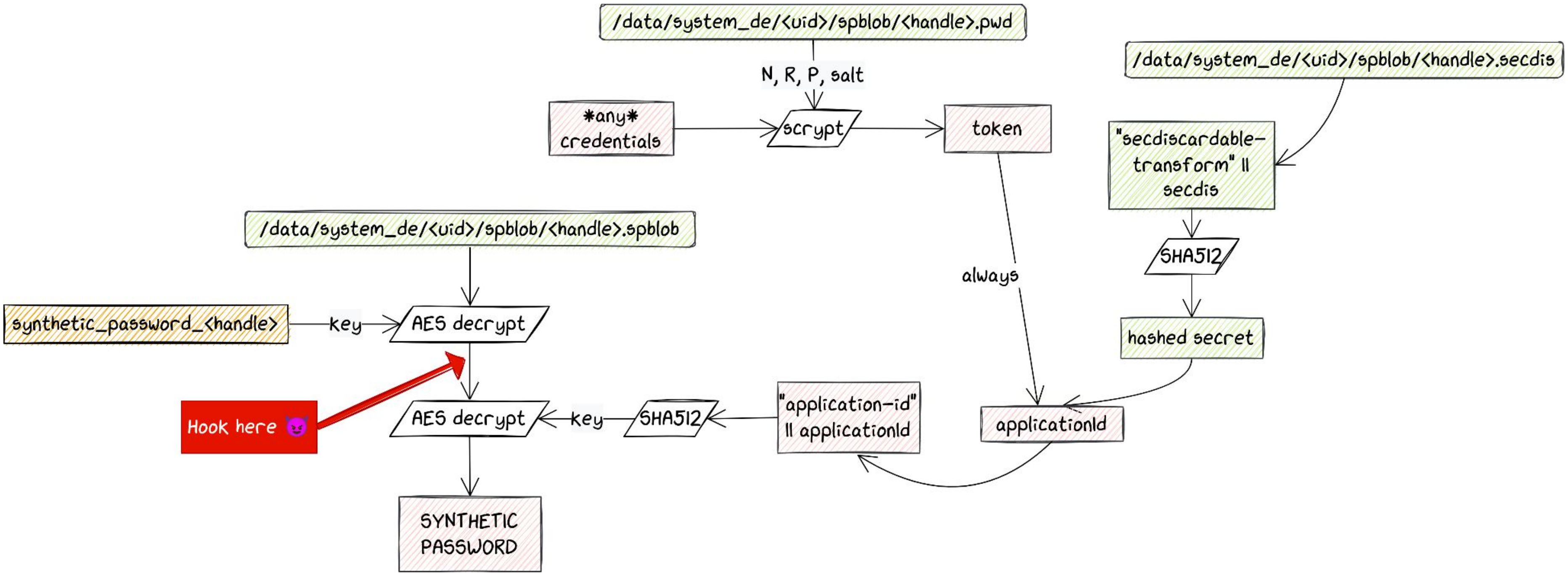
```
iVar1 = TEE_AllocateOperation(&local_30,0x50000004,5,0);
if (iVar1 == 0) {
  iVar1 = TEE_DigestDoFinal(local_30,param_1,param_2,auStack_28,&local_38);
  TEE_FreeOperation(local_30);
  if (iVar1 == 0) {
    uVar2 = TEE_AllocateTransientObject(0xa0000000,param_4 << 3,&local_30);
    if (uVar2 == 0) {
      uVar2 = TEES_DeriveKeyKDF(auStack_28,local_38,local_48,8,param_4,local_30);
      if (uVar2 == 0) {
        uVar3 = 1;
        uVar2 = TEE_GetObjectBufferAttribute(local_30,0xc0000000,param_5,&iStack_34);
        if (uVar2 != 0) {
          uVar3 = 0;
          printf("gatekeeper [ERR] (%s:%u) failed to get object attribute: %x","hal_pwd_hmac",
                 0x12a,(ulong)uVar2);
        }
```

Attack strategy

- Read the output of the first AES decrypt
- Bruteforce credentials to generate `applicationId`
- Thanks to GCM mode, AES decrypt complains if the key is wrong



Hooking system_server

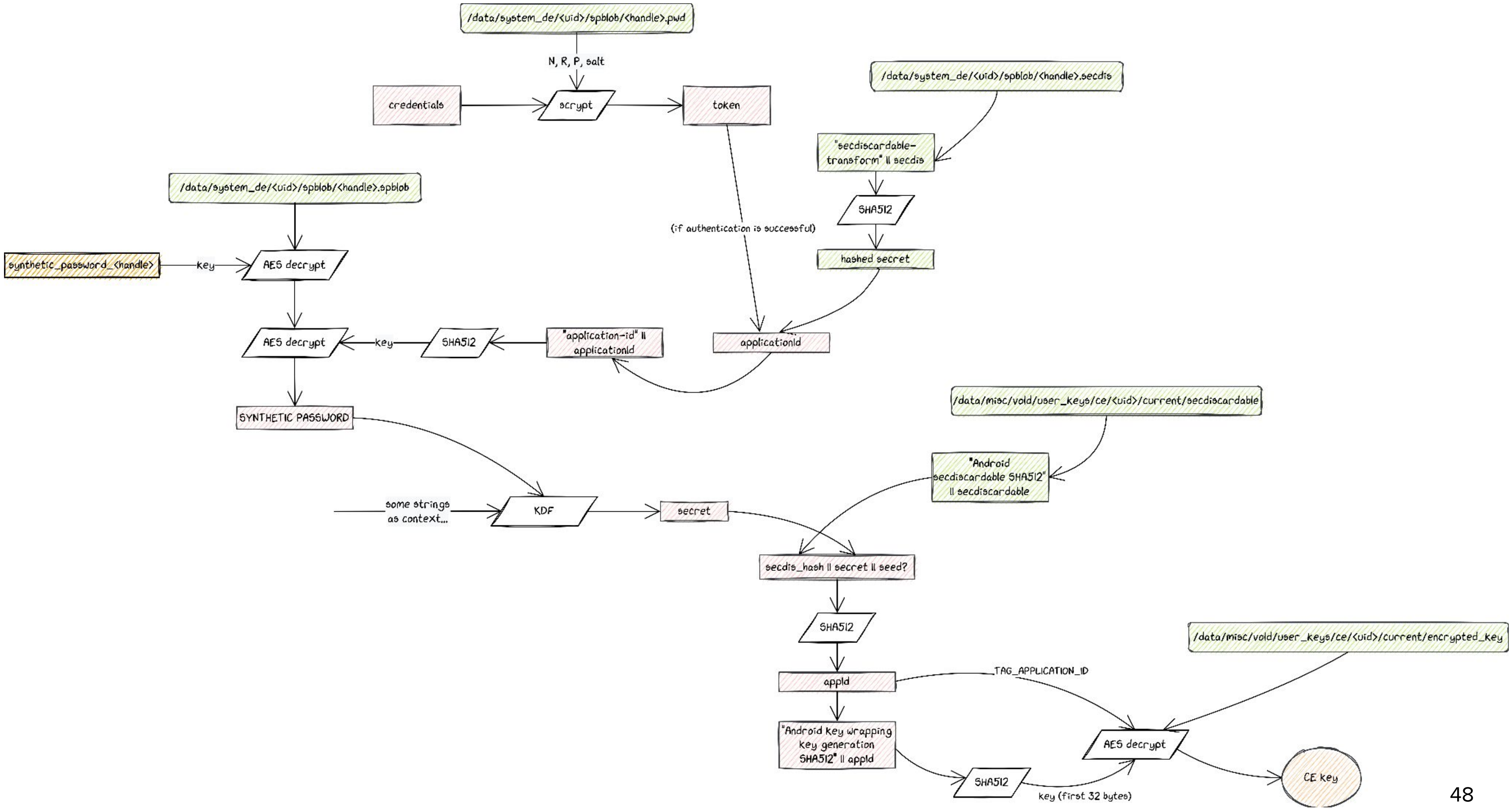


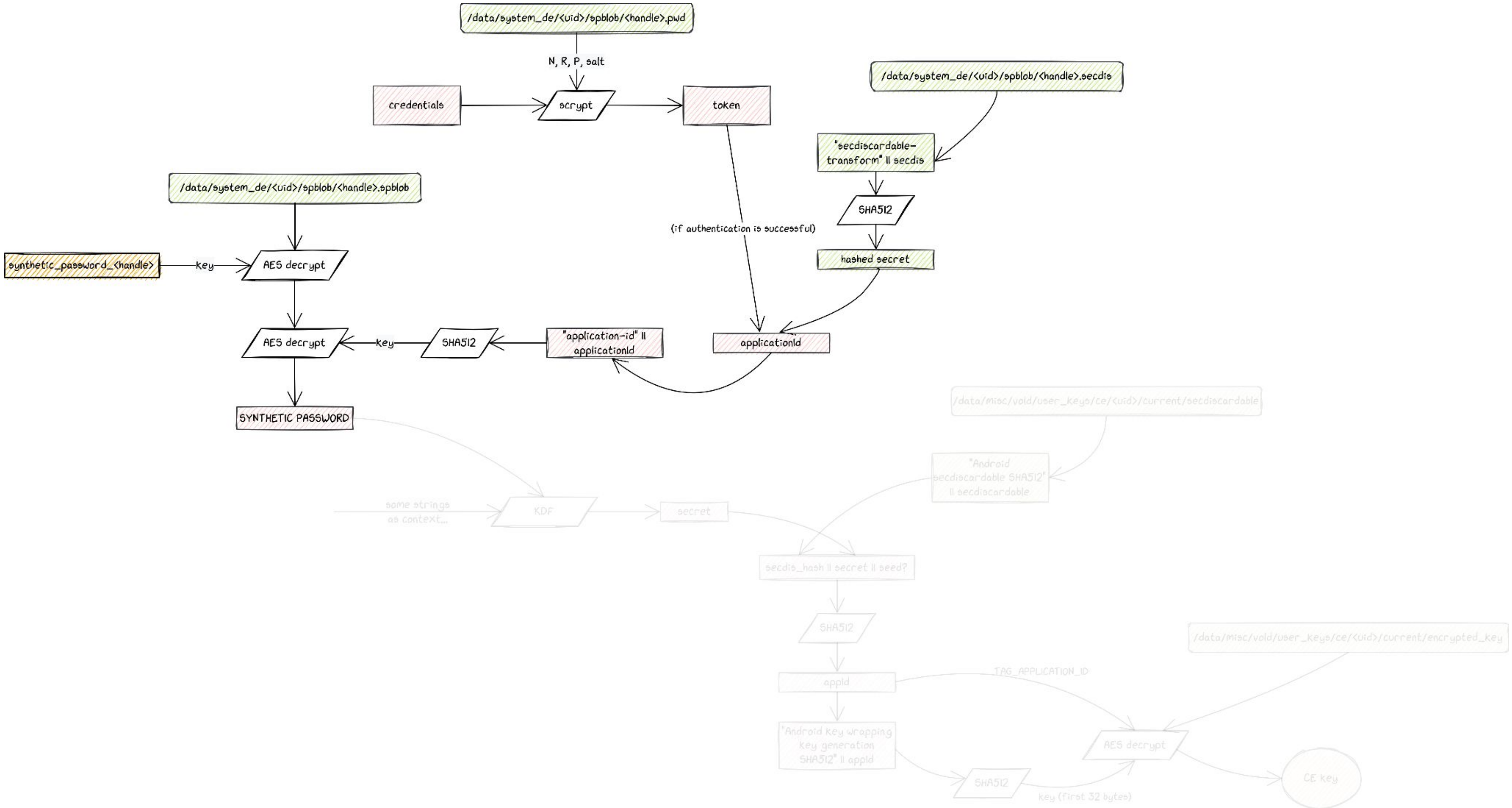
Retrieving intermediate key with Frida

- Use Frida to hook `system_server`
- Retrieve intermediate buffer decrypted by TEE
  - Possible thanks to the auth token

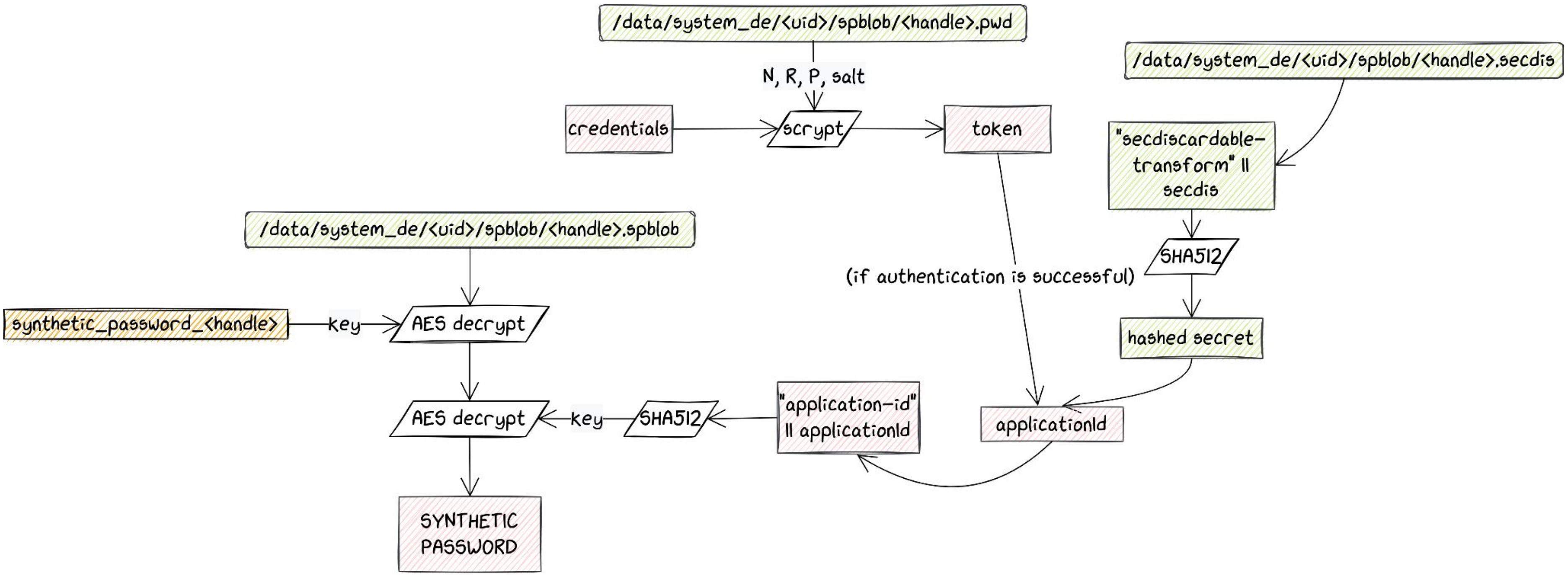
```
$ frida -U system_server -l system_server.js
     ____
    / _  |   Frida 16.0.19 - A world-class dynamic instrumentation toolkit
   | (_| |
    > _  |   Commands:
   /_/ |_|       help      -> Displays the help system
   . . . .       object?   -> Display information about 'object'
   . . . .       exit/quit -> Exit
   . . . .
   . . . .   More info at https://frida.re/docs/home/
   . . . .
   . . . .   Connected to SM A226BR (id=R9WTA0BYDPL)

[SM A226BR::system_server ]-> SyntheticPasswordCrypto.decrypt called!
ciphertext = 641a3ed0a68abdae99976b5aff32f8d5aa4d18127272af6ff638c1e88d57cd157fd6f75b4688465f
470bd4cc81081215e9f2085e4b8ea22e0e8f0ed32a381f641d5cd071d2e177c4a8a1b6e6824f52f251366ff730f66
b7cfd72f11f9761efc5e0cf68bd7bdec00456e07dfb9f1a7f720e97aa262c0507bc87ef46e603a265c821cb1a1dc5
c6f6be6fd43ac3431d0d013de8c9
[SM A226BR::system_server ]->
[SM A226BR::system_server ]->
```

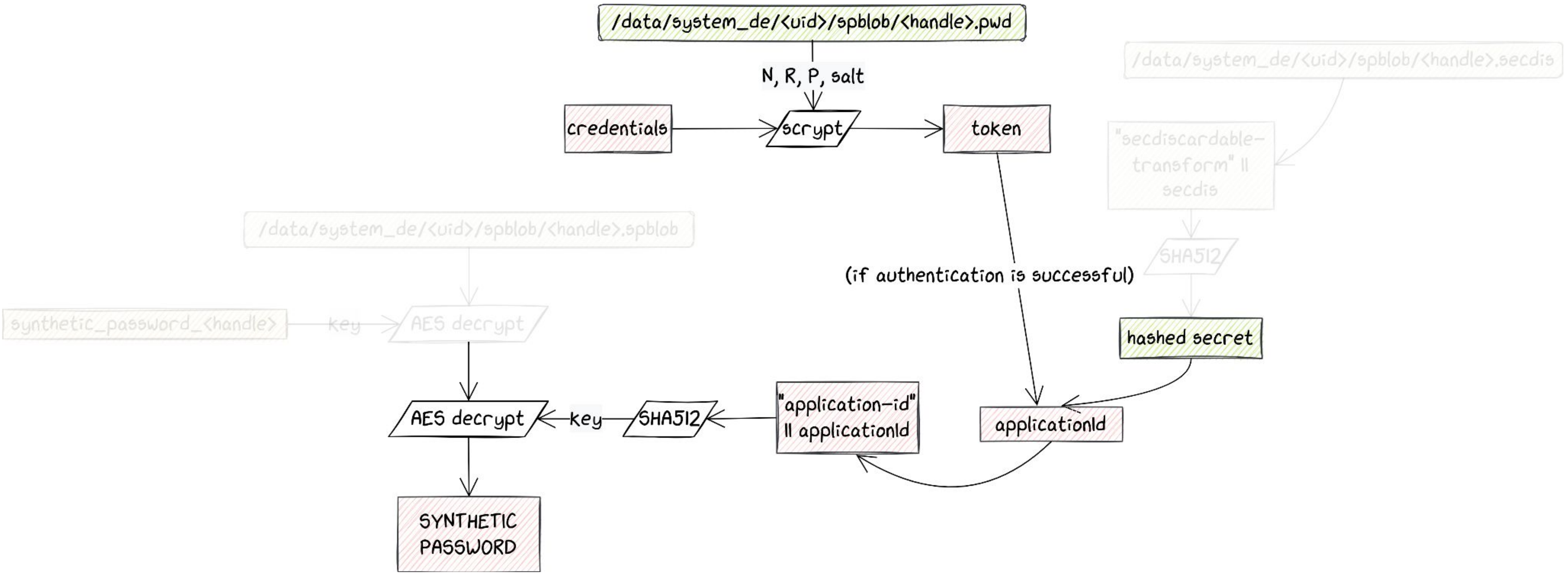

/data/system_de/<uid>/spblob/<handle>.pwd
N, R, P, salt
credentials
scrypt
token
/data/system_de/<uid>/spblob/<handle>.secdis
"secdiscardable-transform" || secdis
SHA512
hashed secret
(if authentication is successful)
/data/system_de/<uid>/spblob/<handle>.spblob
synthetic_password_<handle>
key
AES decrypt
AES decrypt
key
SHA512
"application-id" || applicationId
applicationId
SYNTHETIC PASSWORD
/data/misc/vold/user_keys/ce/<uid>/current/secdiscardable
"Android secdiscardable SHA512" || secdiscardable
some strings as context...
KDF
secret
secdis_hash || secret || seed?
SHA512
appId
TAG_APPLICATION_ID
/data/misc/vold/user_keys/ce/<uid>/current/encrypted_key
"Android key wrapping key generation SHA512" || appId
AES decrypt
SHA512
key (first 32 bytes)
CE key


/data/system_de/<uid>/spblob/<handle>.pwd
N, R, P, salt
credentials
scrypt
token
/data/system_de/<uid>/spblob/<handle>.secdis
"secdiscardable-transform" || secdis
SHA512
hashed secret
(if authentication is successful)
/data/system_de/<uid>/spblob/<handle>.spblob
synthetic_password_<handle>
key
AES decrypt
AES decrypt
key
SHA512
"application-id" || applicationId
applicationId
SYNTHETIC PASSWORD
/data/misc/vold/user_keys/ce/<uid>/current/secdiscardable
"Android secdiscardable SHA512" || secdiscardable
some strings as context...
KDF
secret
secdis_hash || secret || seed?
SHA512
appId
TAG_APPLICATION_ID
/data/misc/vold/user_keys/ce/<uid>/current/encrypted_key
"Android key wrapping key generation SHA512" || appId
AES decrypt
SHA512
key (first 32 bytes)
CE key

Bruteforce of the password



Bruteforce of the password



Bruteforce of the password

1. `pwd = generate new password`
2. `token =` **`scrypt`**`(pwd, R, N, P, Salt)`
3. `Application_id = token || Prehashed value`
4. `Key =` **`SHA512`**`("application_id" || application_id)`
5. **`AES_Decrypt`**`(value_from_keymaster, key)`

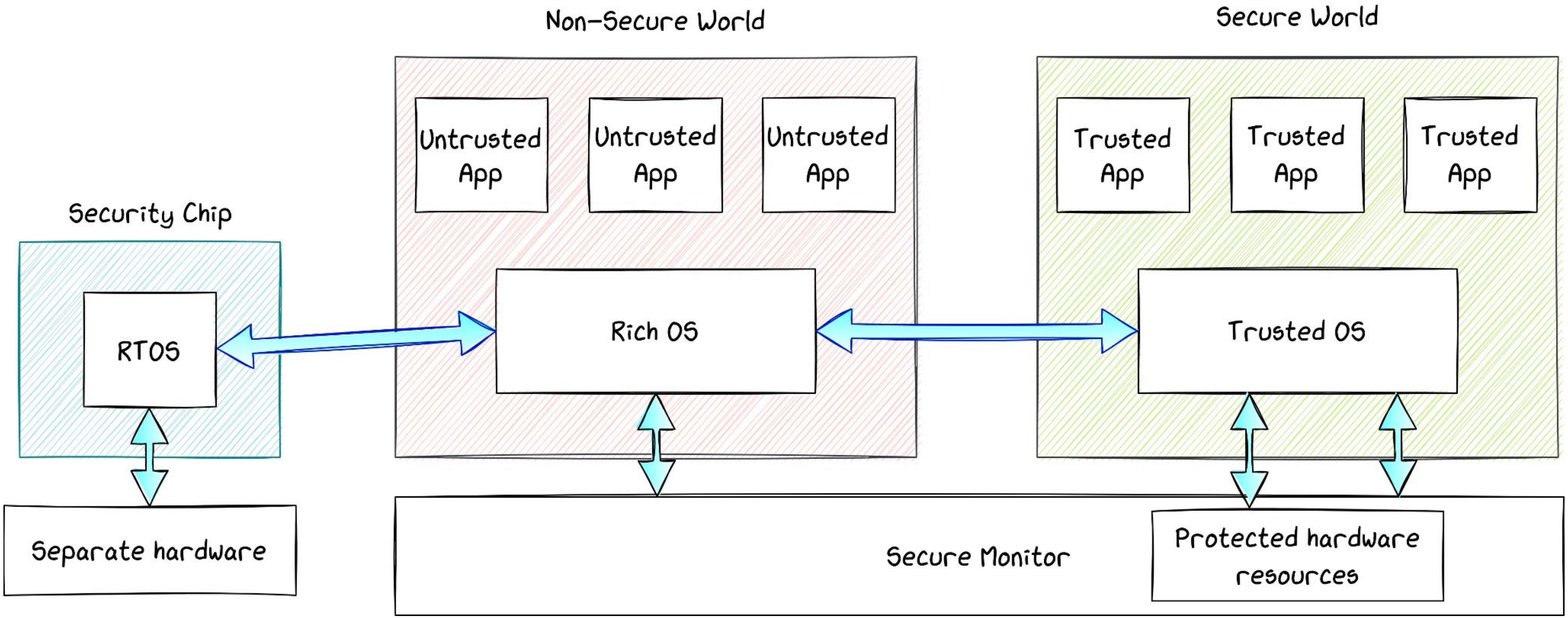
Bruteforce of the password

1. pwd = generate new password
2. token = **scrypt**(pwd, R, N, P, Salt)
3. Application_id = token || Prehashed value
4. Key = **SHA512**("application_id" || application_id)
5. **AES_Decrypt**(value_from_keymaster, key)

```
$ python3 bruteforce-tee.py
workers will cycle through the last 5 chars
Found it: 1234
the plaintext is '1234'
Done in 18.031058311462402s
Throughput: 1478.448992816657 tries/s
```

Demo 1

Architecture w/ Trusted Chip



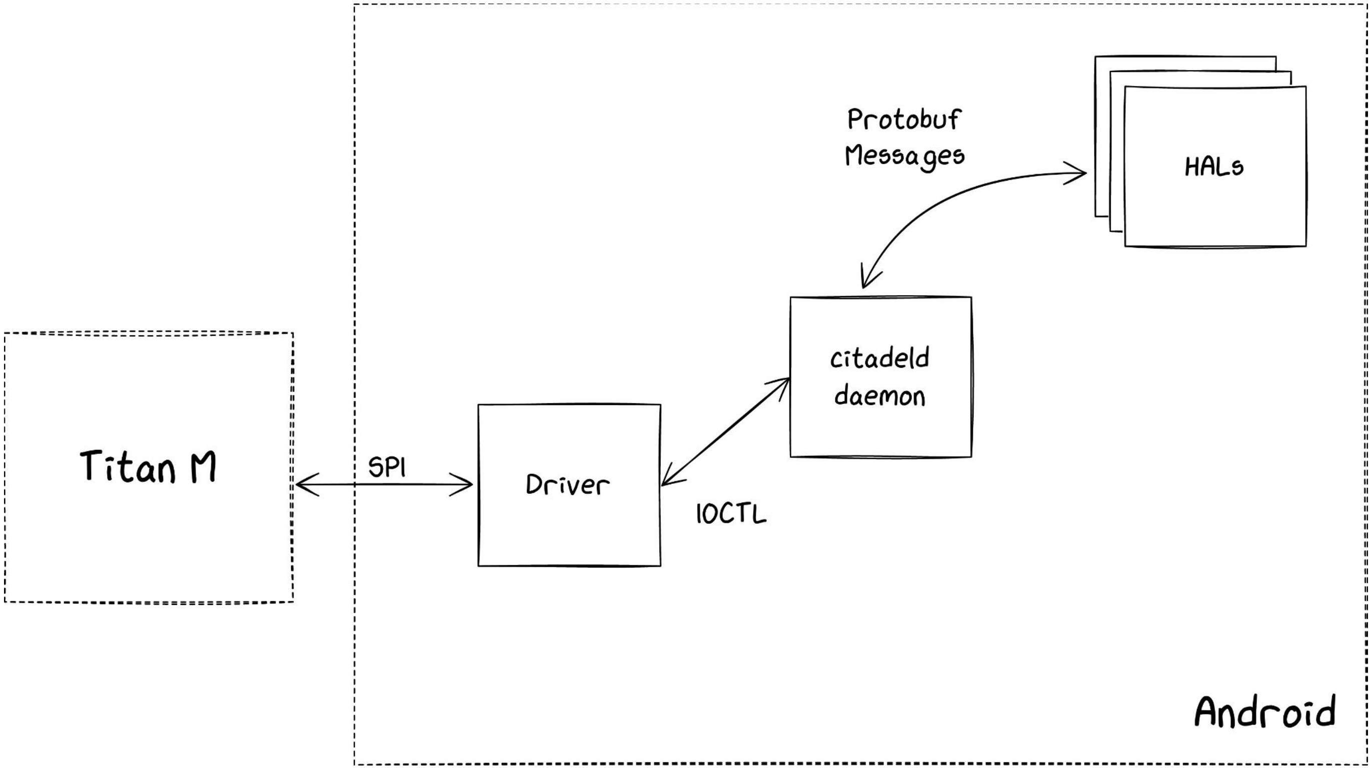
The Titan M Chip

- Security chip made by Google for Pixel phones
- From Pixel 3 to Pixel 5a
  - In this PoC we use a Pixel 3a
  - Titan M2 introduced from Pixel 6
- Based on Arm Cortex-M3
- Most of the code is divided into tasks
  - Keymaster (Strongbox), **Weaver**, AVB, etc
- Separate memory and resources
  - Communicates with Android on SPI bus

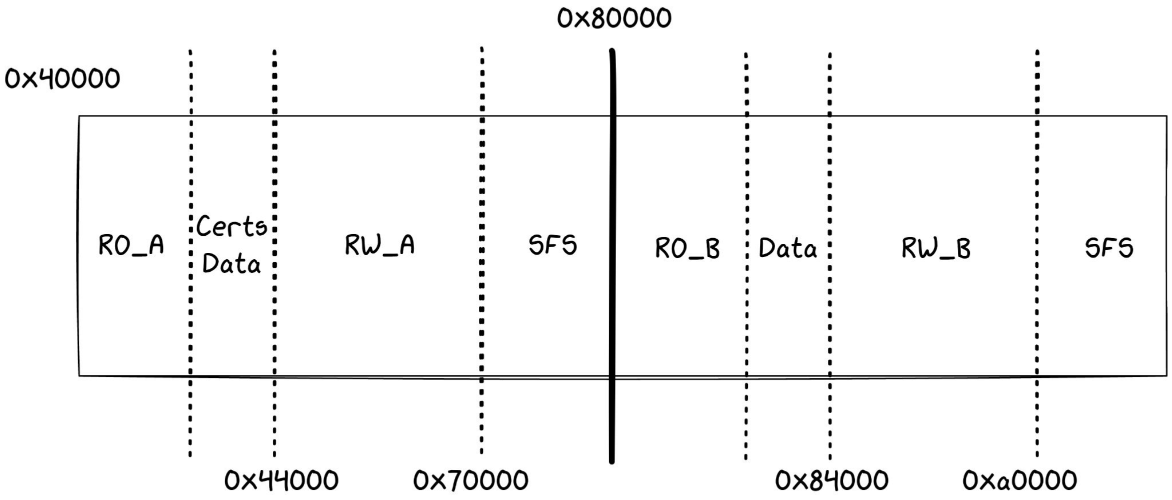
Trusted chip vs TrustZone

- In TrustZone, secure and normal world run on the same CPU
  - Shared hardware (cache, RAM)
  - Side-channel attacks are possible (e.g. Rowhammer)
- Titan M relies on tamper-resistant hardware
- Separate firmware
  - Limited in size
  - Conceptually simple
  - Isolated from the rest of the system

Communication with the chip



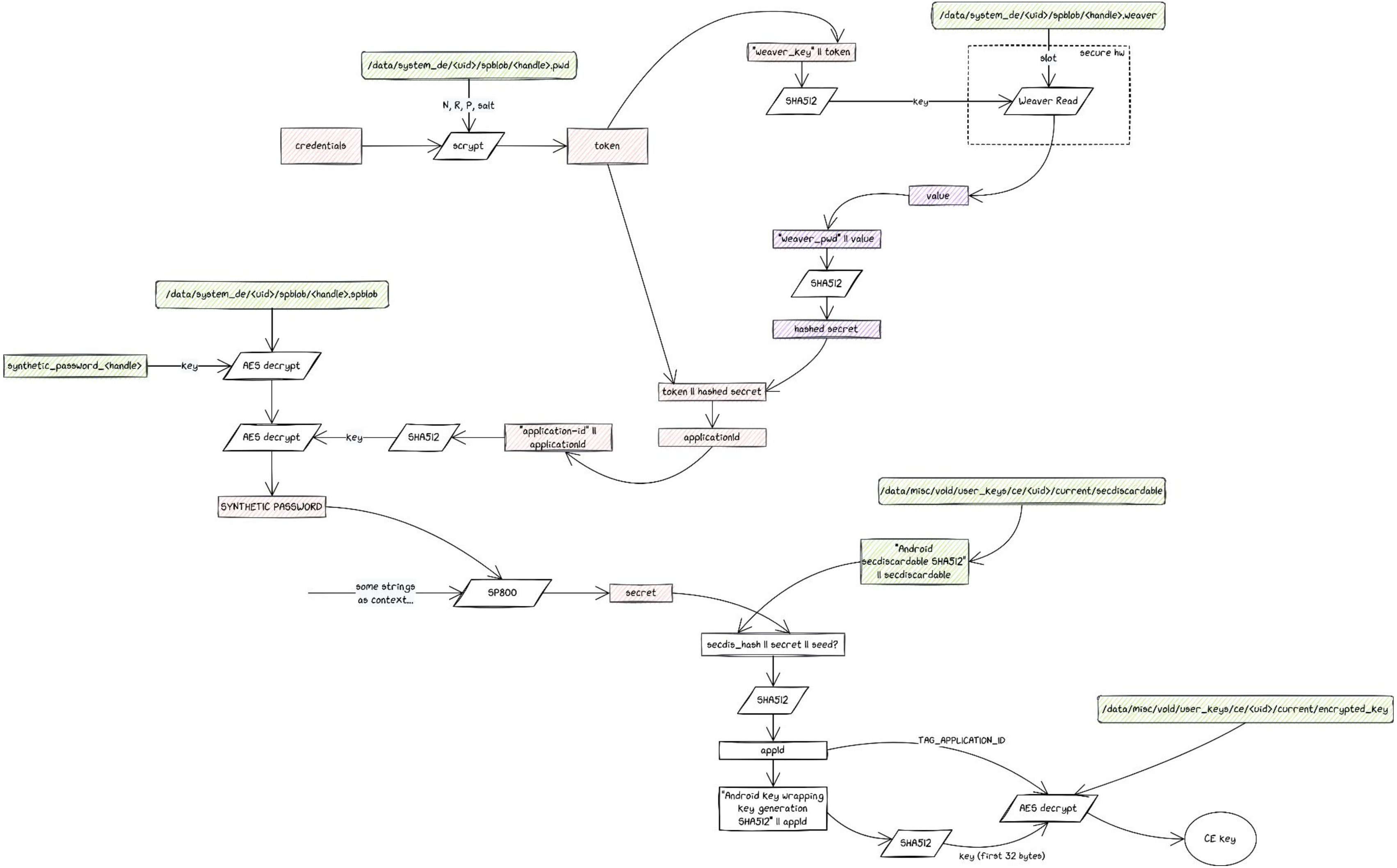
Memory Layout

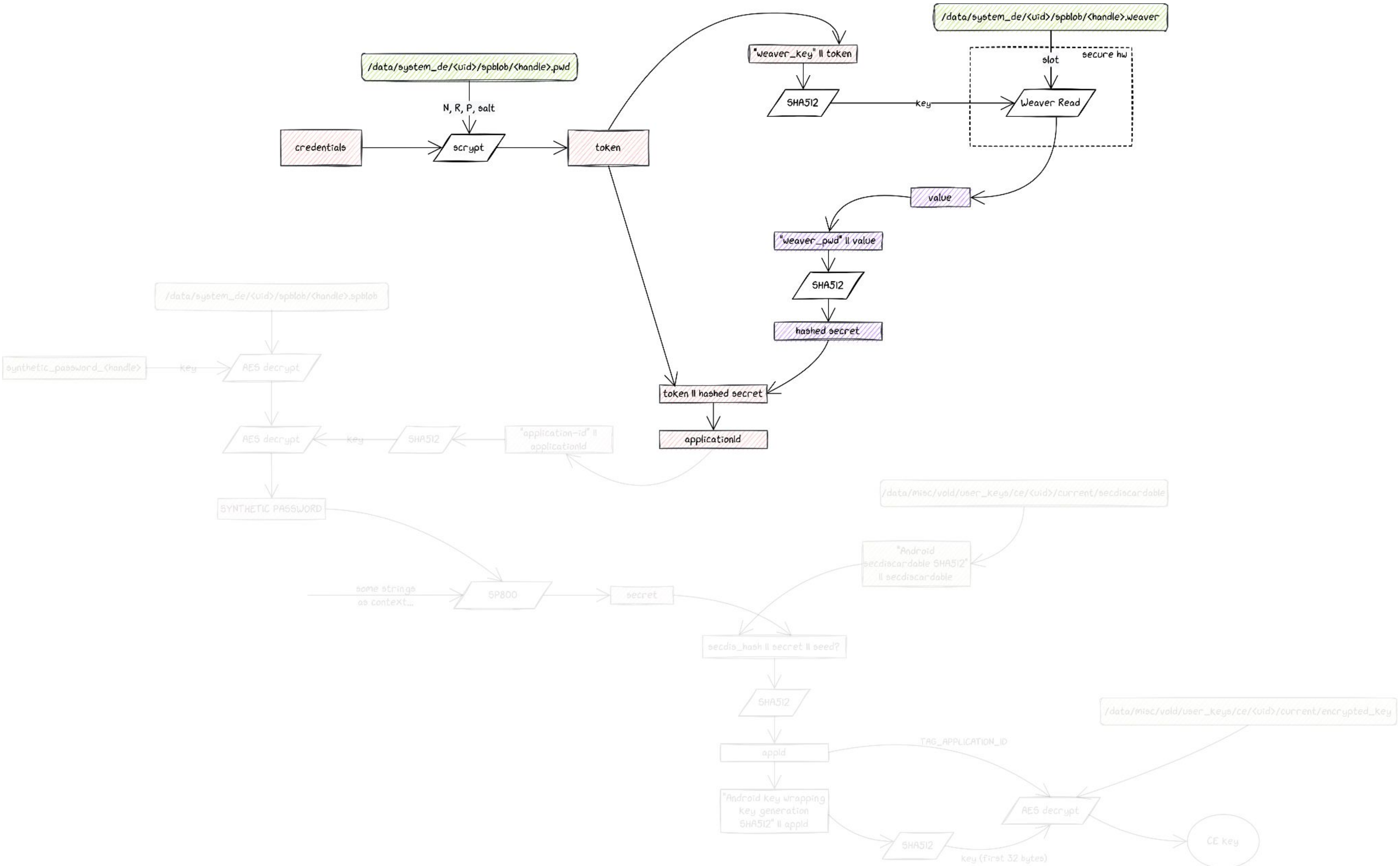


Weaver

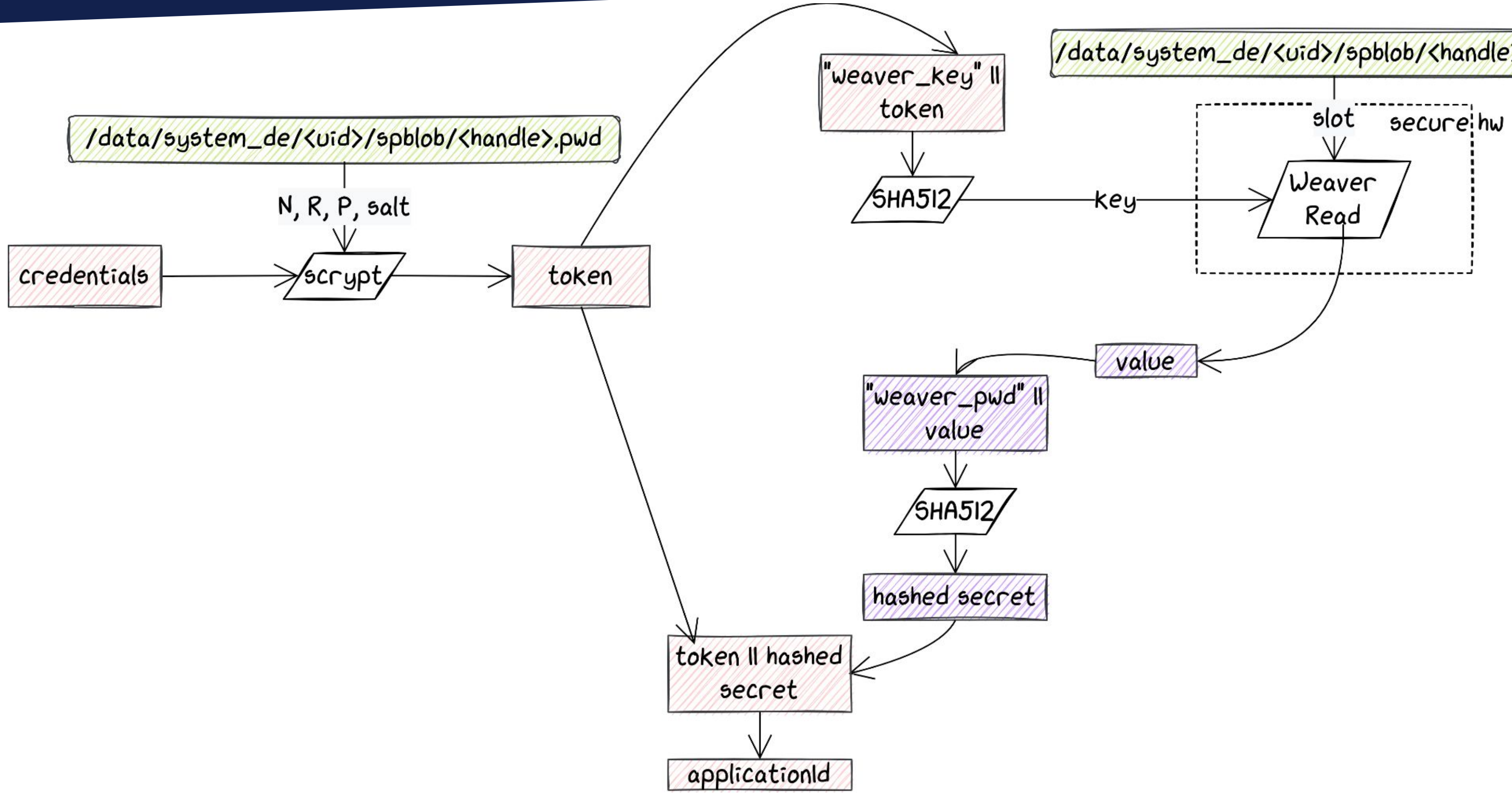
- Key/Value storage
  - Stored in `slots`
  - In two differents places in the flash memory
- 4 commands: `GetConfig`, `Read`, `Write`, `Erase`
- Implements throttling as well

```
// Read
message ReadRequest {
  uint32 slot = 1;
  bytes key = 2;
}
message ReadResponse {
  Error error = 1;
  uint32 throttle_msec = 2;
  bytes value = 3;
}
```


/data/system_de/<uid>/spblob/<handle>.pwd
N, R, P, salt
credentials
scrypt
token
"weaver_key" || token
SHA512
key
/data/system_de/<uid>/spblob/<handle>.weaver
slot
secure hw
Weaver Read
value
"weaver_pwd" || value
SHA512
hashed secret
token || hashed secret
applicationId
/data/system_de/<uid>/spblob/<handle>.spblob
synthetic_password_<handle>
key
AES decrypt
AES decrypt
key
SHA512
"application-id" || applicationId
SYNTHETIC PASSWORD
/data/misc/vold/user_keys/ce/<uid>/current/secdiscardable
"Android secdiscardable SHA512" || secdiscardable
some strings as context...
SP800
secret
secdis_hash || secret || seed?
SHA512
appId
TAG_APPLICATION_ID
/data/misc/vold/user_keys/ce/<uid>/current/encrypted_key
"Android key wrapping key generation SHA512" || appId
AES decrypt
CE key
SHA512
key (first 32 bytes)


/data/system_de/<uid>/spblob/<handle>.weaver
"weaver_key" || token
secure hw
slot
SHA512
key
Weaver Read
/data/system_de/<uid>/spblob/<handle>.pwd
N, R, P, salt
credentials
scrypt
token
value
"weaver_pwd" || value
SHA512
hashed secret
token || hashed secret
applicationId
/data/system_de/<uid>/spblob/<handle>.spblob
synthetic_password_<handle>
key
AES decrypt
AES decrypt
key
SHA512
"application-id" || applicationId
SYNTHETIC PASSWORD
/data/misc/vold/user_keys/ce/<uid>/current/secdiscardable
"Android secdiscardable SHA512" || secdiscardable
some strings as context...
SP800
secret
secdis_hash || secret || seed?
SHA512
/data/misc/vold/user_keys/ce/<uid>/current/encrypted_key
appId
TAG_APPLICATION_ID
"Android key wrapping key generation SHA512" || appId
AES decrypt
SHA512
key (first 32 bytes)
CE key

CE key derivation with Weaver



PoC on Google Pixel

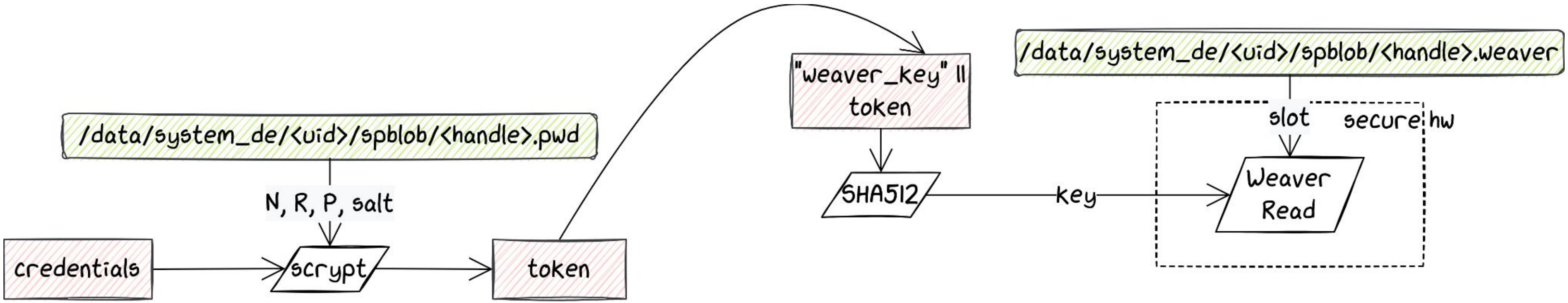
- We consider the device being already rooted
- Weaver relies on the security chip Titan M
- Here we exploit CVE-2022-20233 to execute code on the chip
- Out-of-bounds write of 1 byte to `0x1`
  - Can be repeated multiple times
  - Huge constraints on the offset
  - We managed to overwrite a global field and cause another corruption
- Full exploit write-up in our blog[8]

[8]: https://blog.quarkslab.com/attacking-titan-m-with-only-one-byte.html

Nosclient and the leak command

- We built a client to communicate with Titan M, `nosclient`
- “Leak” feature:
  - `./nosclient leak <address> <size>`
  - Read `<size>` bytes from `<address>`
  - ➜ Arbitrary read in Titan M’s memory
- Weaver slots and values are stored in flash
  - Reverse engineering to understand a memory range
  - Then search for 16 bytes digests
  - Weaver `Write` and `Read` help out

Our Strategy



1. Leak the Weaver key
2. Use it to compare our generated credentials

Bruteforce of the password

1. `pwd = generate new password`
2. `token =` **`scrypt`**`(pwd, R, N, P, Salt)`
3. `key =` **`SHA512`**`("weaver_key" || token)`
4. `Compare with leaked Weaver key`

```
$ python3 bruteforce.py
workers will cycle through the last 5 chars
Found it: 1106
the plaintext is'1106'
Done in 15.063793659210205 s
Throughput: 1491.722504195411 tries/s
```

Demo 2

Conclusion

- FBE is very well designed
- Ingredients from “everywhere” are used to derive the key
  - Files owned by privileged users
  - TEE-protected keys
  - Weaver values (when available)
- Multiple bugs needed to break it
  - Or a very powerful one
- You still need to bruteforce credentials in the end
- “`my very secret password example for Hardwear.io 2023`” will be hard to guess :)

Thank you!

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contact@quarkslab.com

Quarkslab

Little Kernel

LK: Android bootloader based on Little Kernel

- Allows to boot Android or other modes (Recovery)
- Loads TZAR image in TEEGRIS
- Implements **A**ndroid **V**erified **B**oot v2
  - Verification of Android images
  - Involving boot and vbmeta images
  - Anti-rollback

TZAR image

Trust**Z**one **AR**chive: contains a root filesystem

- Shared libraries
- Binaries
- `tzinitd` (init binary)
- `root_task`

```
├── bin
│   ├── 00000005-0005-0005-0505-050505050505
│   └── 00000007-0007-0007-0707-070707070707
├── etc
│   ├── propd
│   │   └── build_sl.prop
│   └── tzinitd
│       ├── crypto.tzrc
│       ├── init.release.tzrc
│       ├── init.tzrc
│       ├── ...
├── lib32
│   ├── libaudit_aux.so
│   ├── libc++.so
│   ├── ...
├── lib64
│   ├── libaudit_aux.so
│   ├── libc++.so
│   ├── ...
├── sbin
│   ├── propd
│   └── root_task
└── tzinitd
```

Patching TEEGRIS

Our final goal is to run a modified Gatekeeper TA

- Patch `userboot.so` from the `tee1` partition
  - Disable verification of `TZAR` image
- Patch `root_task` from the `TZAR` image
  - Disable verification of `TA`
- Patch the `Gatekeeper` TA
  - Accept any credentials and return a valid auth token