LABSCON

PKfail: Supply-Chain Failures in Secure Boot Key Management

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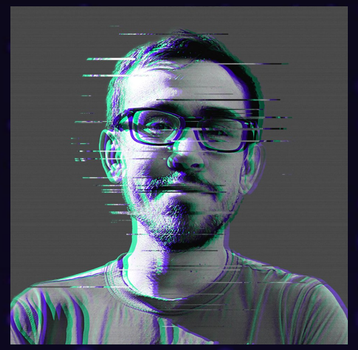
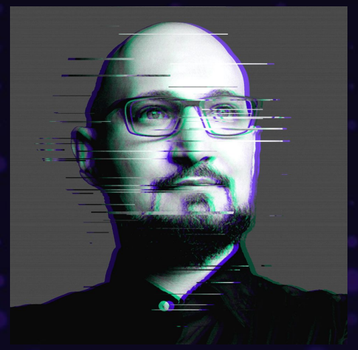
binarly

Binarly REsearch Team — PKfail Edition

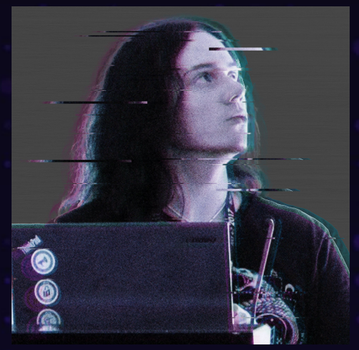


Fabio Pagani
@pagabuc

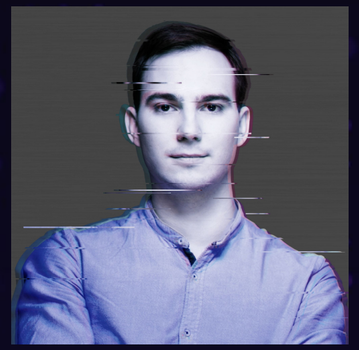


Alex Matrosov
@matrosov

Yegor Vasilenko
@yeggorv



Sam Thomas
@xorpse



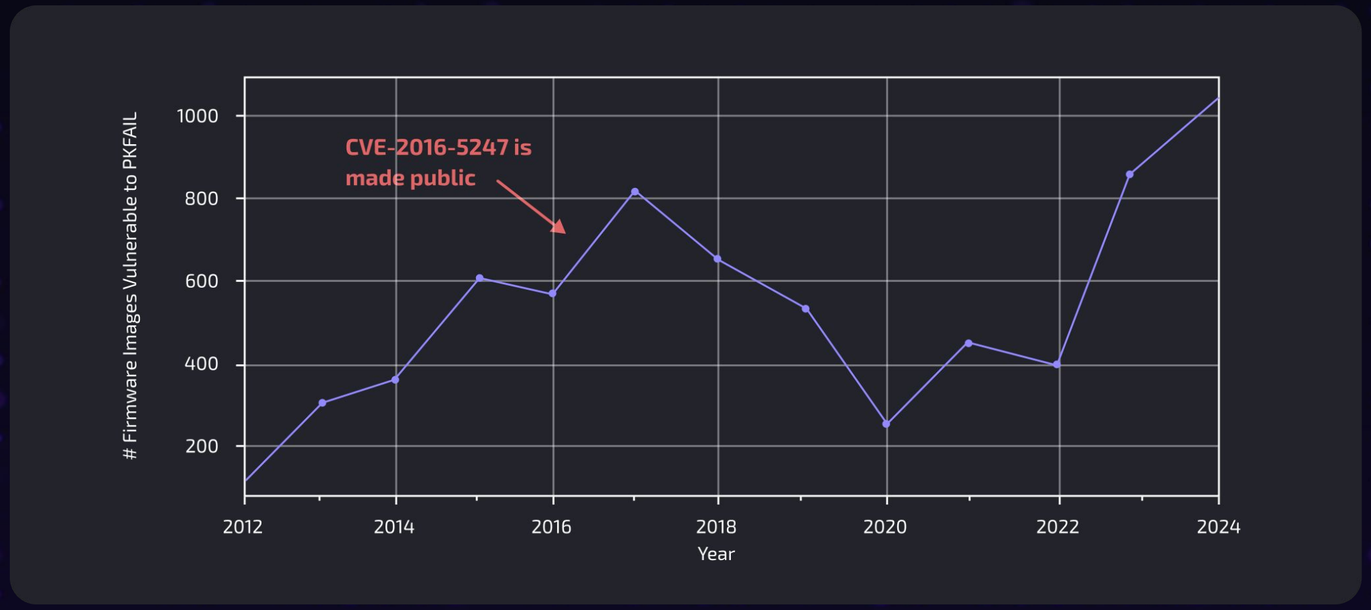
Anton Ivanov
@ant_av7

Agenda

- The Beginning
- Discovery and Disclosure
- PKfail: Exploitation and PoC Demo
- New Discovery: MicroFAIL
- Conclusion

PKfail:
The Beginning

Retrospective view on PKfail



PK Test Key
CVE-2016-5247
2016

AMI
Leaked PK detected
2018

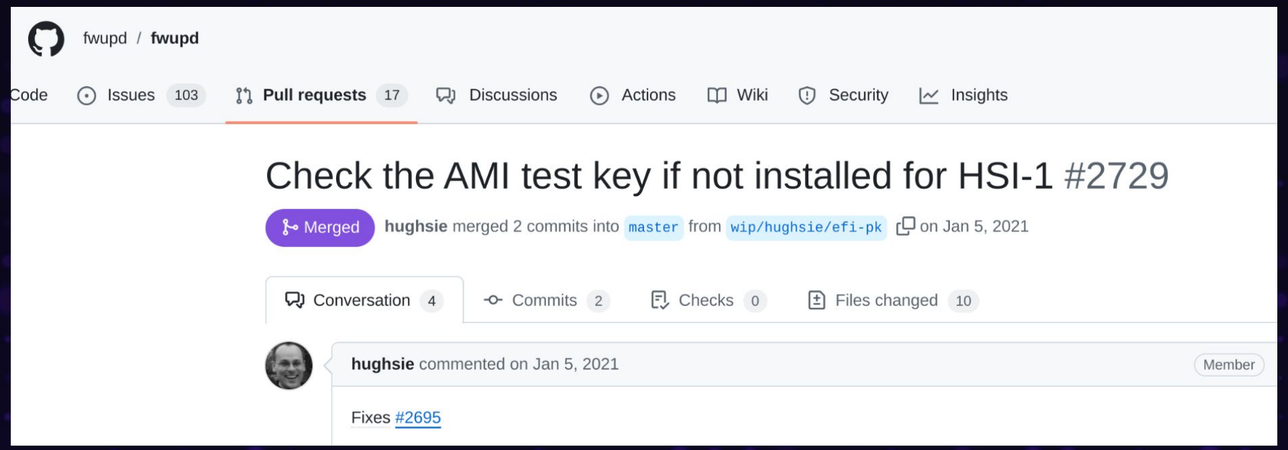
LVFS
Detect test keys
2019

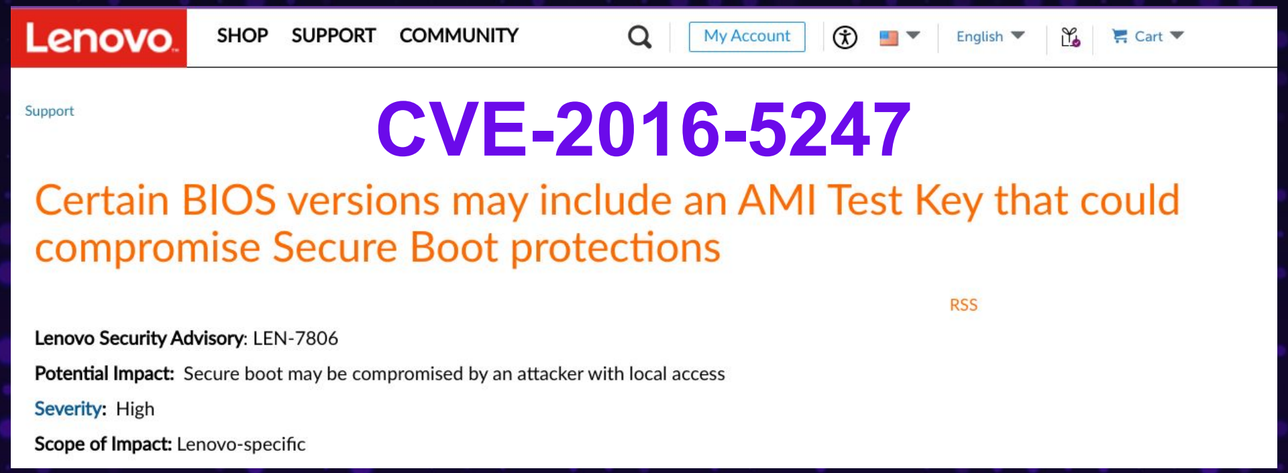
Key Leaked
2022

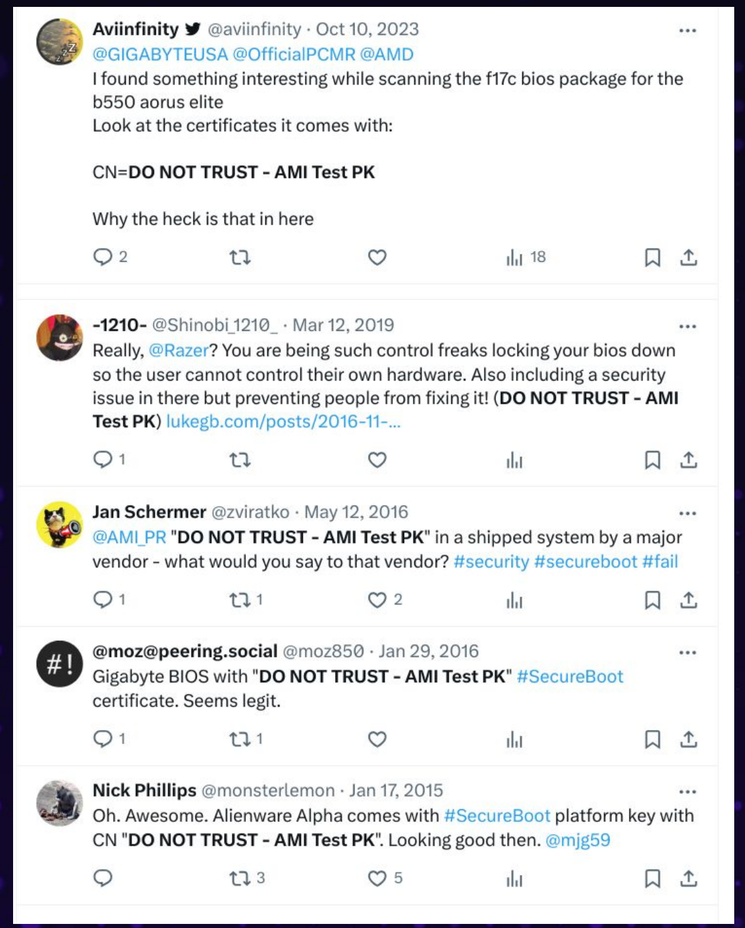
PKfail
2024

Turns out that …

This is an already known problem! o_O

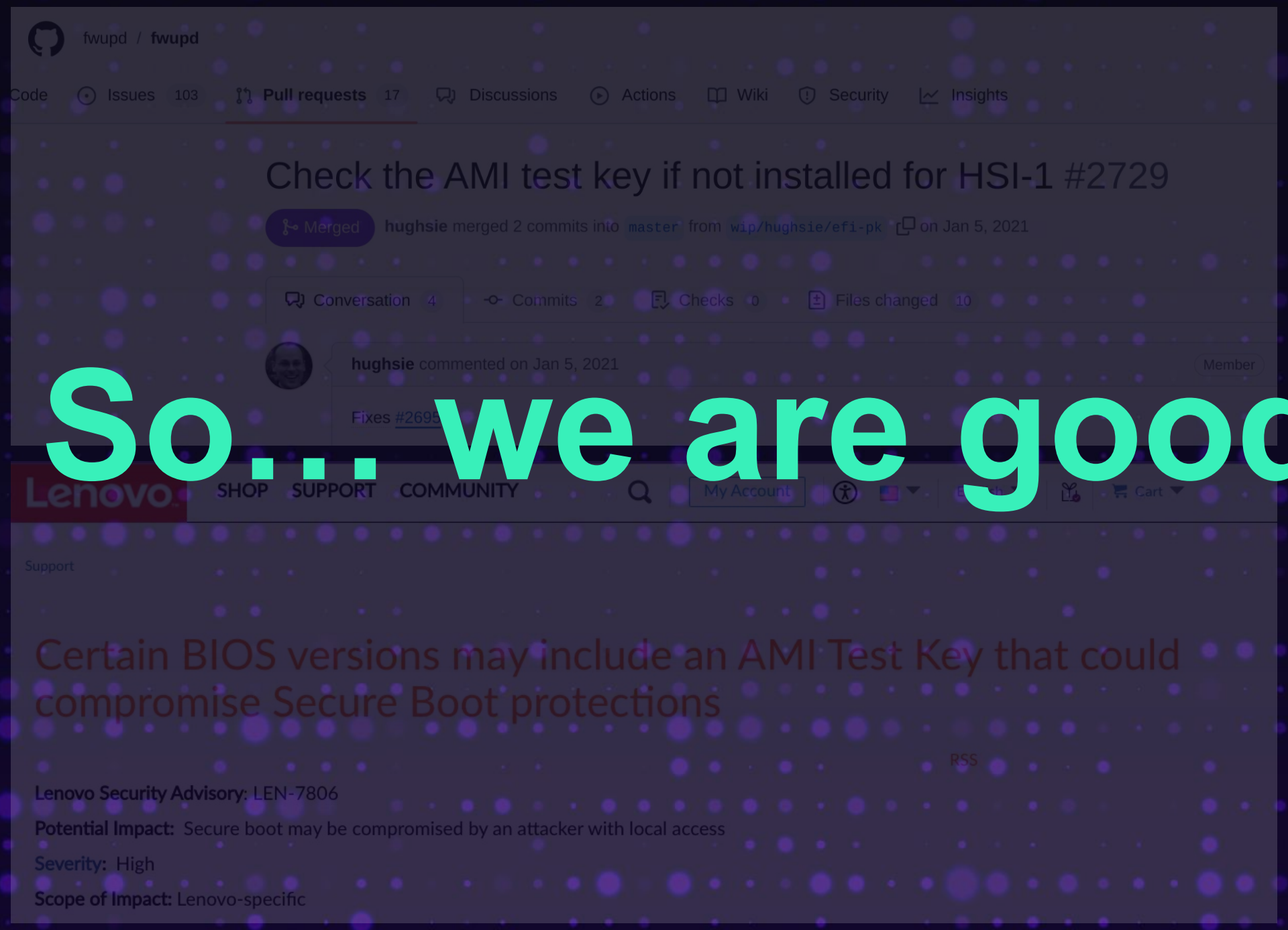






Turns out that …

This is an already known problem! o_O



So… we are good, RIGHT?

Retrospective view on PKfail

Dataset with 80,000 UEFI firmware images:

- Spanning over 10 years
- Includes every major vendor (Lenovo, Dell, HP, Intel..)

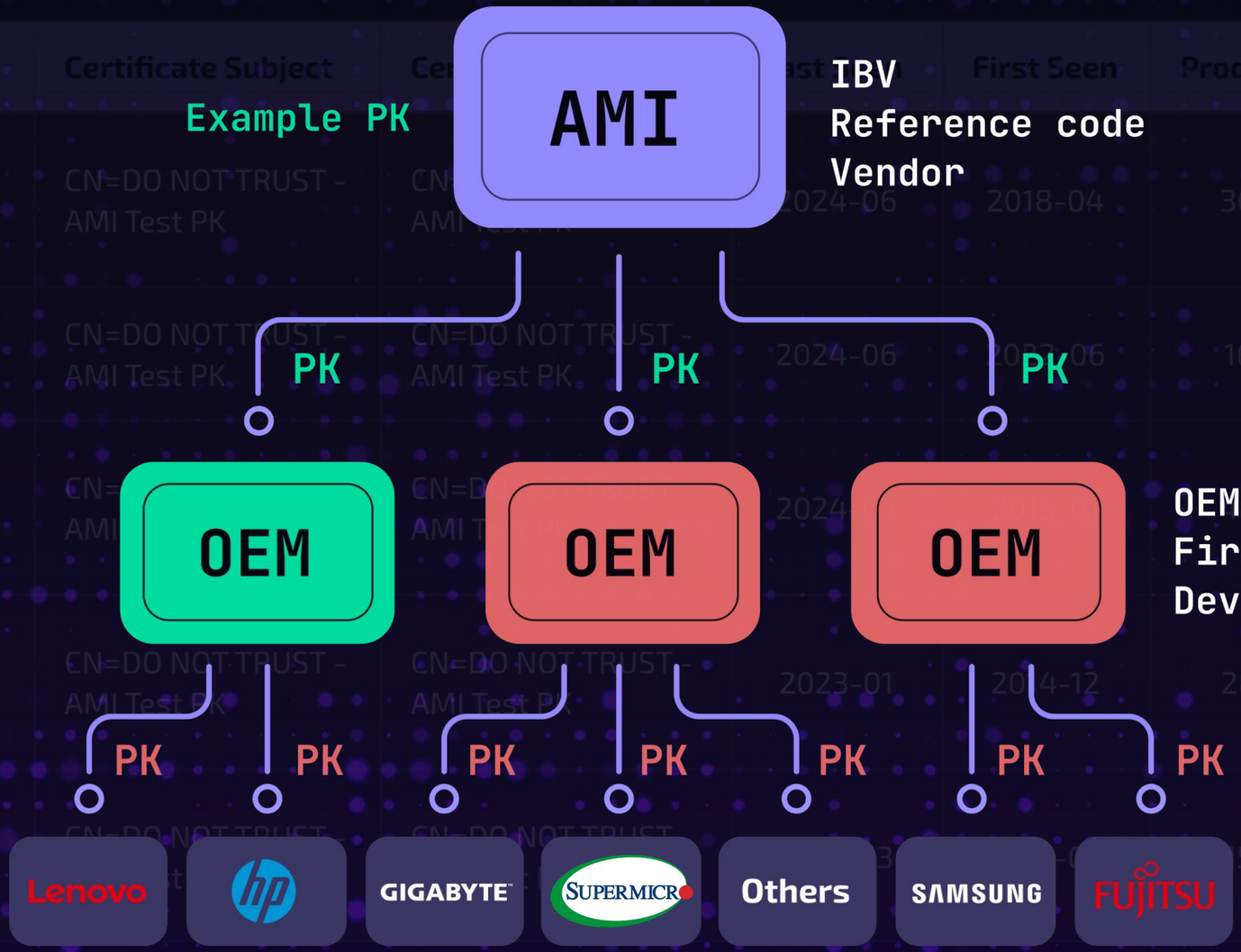
Results:

- 10% of images use non-production keys
- 8% of images when selecting images released in the past 4 years
- 22 unique non-production keys identified

Retrospective view on PKfail

Certificate Serial Number	Certificate Subject	Certificate Issuer	Last Seen	First Seen	Products	Vendors
55:fb:ef:87:81:23:00:84:47:17:0b:b3:cd:87:3a:f4	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2024-06	2018-04	364	Acer, Dell, Fujitsu, Gigabyte, Intel, Lenovo,Supermicro
-08:c2:d1:c3:6c:9b:51:4f:b3:7c:6a:02:08:12:cd:59	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2024-06	2022-06	167	Acer, Dell, Gigabyte, Supermicro
-15:fe:0d:04:9b:3b:74:70:bc:6f:1a:d2:96:ed:c4:7b	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2024-03	2015-01	483	Acer, Dell, Gigabyte, Intel, Lenovo, Supermicro
-1b:ed:93:e2:59:4e:2b:60:be:6b:1f:01:c9:af:a6:37	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2023-01	2014-12	287	Dell, Fujitsu, Gigabyte, HP, Intel, Lenovo, Supermicro
1a:a9:c7:61:c8:6a:be:88:4d:85:f5:ad:2b:95:3b:f1	CN=DO NOT TRUST - AMI Test PK	CN=DO NOT TRUST - AMI Test PK	2021-03	2012-05	157	Acer, Dell, Fujitsu, Gigabyte, HP, Lenovo, Samsung, Supermicro

Retrospective view on PKfail



A leaked PK appears 

Multiple leaks – either by hacking
or by “accident” – affected UEFI ecosystem

```
pagabuc@trin/tmp/Ryzen2000_4000/Keys/FW/AmiTest$ openssl pkcs12 -in FW_priKey.pfx -nodes -out PK.key
Enter Import Password:
```

```
pagabuc@trin/tmp/Ryzen2000_4000/Keys/FW/AmiTest$ cat AmiTestKey.sdl

TOKEN
        Name  = "FW_PFX_Password"
        Value  = "abcd"
        Help  = "Specifies the password to use when opening a PFX - Private Key container file."
        TokenType = Expression
        TargetMAK = Yes
End
```

Oh, hi! I am a private key
that’s been available
on GitHub for 6 months! 🤦

A leaked PK appears 

Multiple leaks – either by hacking
or by “accident” – affected UEFI ecosystem

This key has been included in firmware released between 2018 and now.

- **01-18-2023:** The `Ryzen2000_4000` repo is created on GitHub
- **04-14-2023:** Repository is uploaded on the Internet Archive
- **05-??-2023:** The `Ryzen2000_4000` repo is deleted by the owner
- **06-06-2023:** All remaining forks on GitHub are DMCA’d by AMI

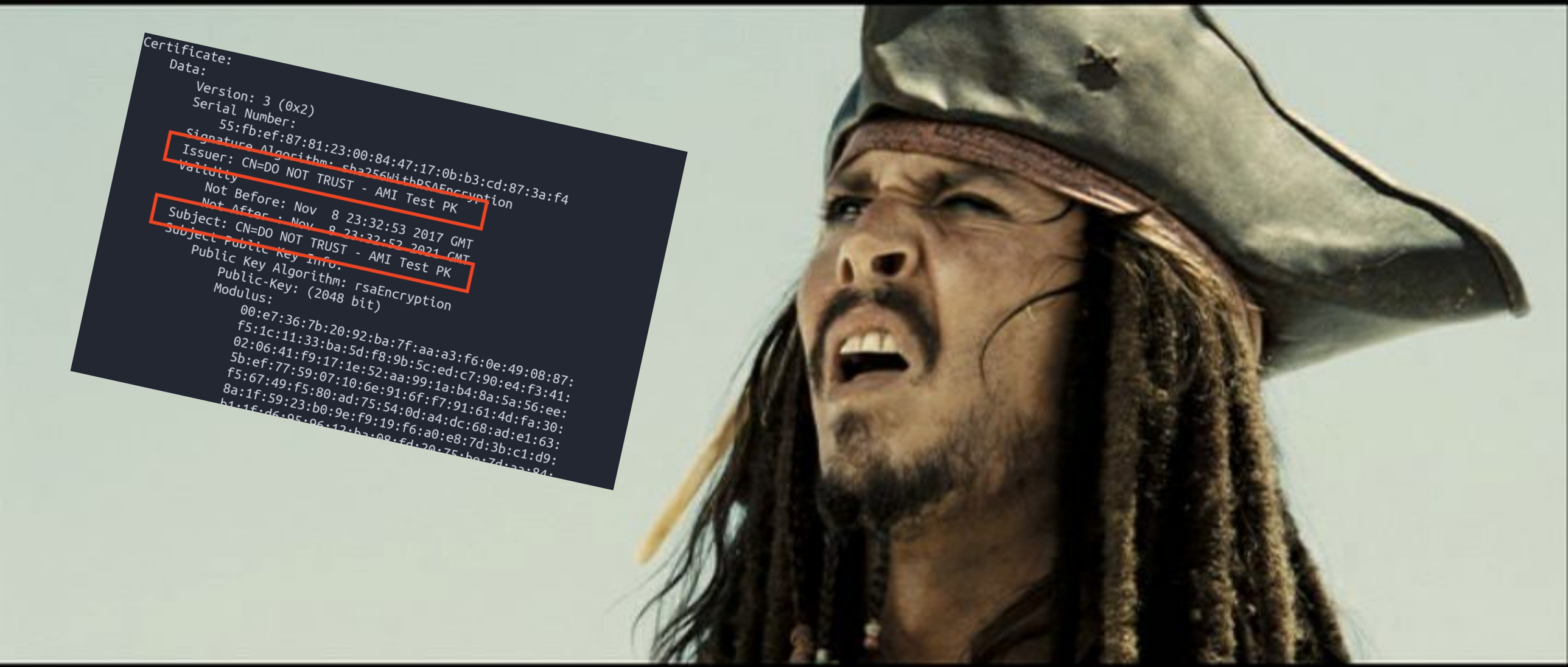
PKfail: Discovery and Disclosure

The discovery of PKfail

Earlier this year, we were adding support to our platform for reporting outdated Forbidden Secure Boot database* when…

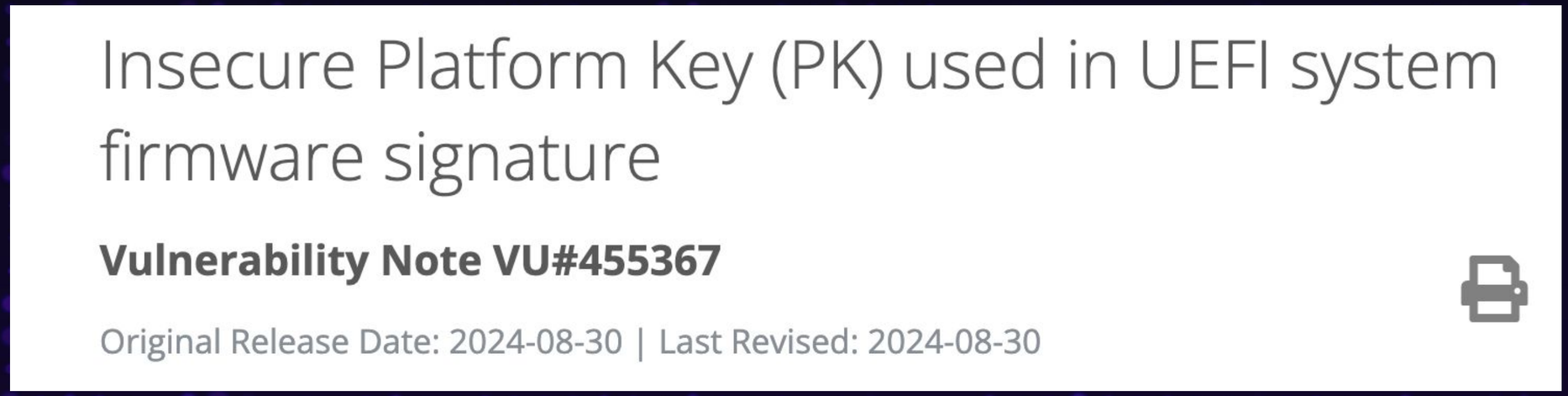
```
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            55:fb:ef:87:81:23:00:84:47:17:0b:b3:cd:87:3a:f4
        Signature Algorithm: sha256WithRSAEncryption
        Issuer: CN=DO NOT TRUST - AMI Test PK
        Validity
            Not Before: Nov  8 23:32:53 2017 GMT
            Not After : Nov  8 23:32:52 2021 GMT
        Subject: CN=DO NOT TRUST - AMI Test PK
        Subject Public Key Info:
            Public Key Algorithm: rsaEncryption
                Public-Key: (2048 bit)
                Modulus:
                    00:e7:36:7b:20:92:ba:7f:aa:a3:f6:0e:49:08:87:
                    f5:1c:11:33:ba:5d:f8:9b:5c:ed:c7:90:e4:f3:41:
                    02:06:41:f9:17:1e:52:aa:99:1a:b4:8a:5a:56:ee:
                    5b:ef:77:59:07:10:6e:91:6f:f7:91:61:4d:fa:30:
                    f5:67:49:f5:80:ad:75:54:0d:a4:dc:68:ad:e1:63:
                    8a:1f:59:23:b0:9e:f9:19:f6:a0:e8:7d:3b:c1:d9:
                    b1:1f:d6:95:96:12:ba:08:fd:20:75:be:7d:aa:84:
```

* Stay tuned for an upcoming blogpost on this topic!


Certificate:
Data:
Version: 3 (0x2)
Serial Number:
55:fb:ef:87:81:23:00:84:47:17:0b:b3:cd:87:3a:f4
Issuer: CN=DO NOT TRUST - AMI Test PK
Validity
Not Before: Nov 8 23:32:53 2017 GMT
Subject: CN=DO NOT TRUST - AMI Test PK
Public Key Algorithm: rsaEncryption
Public-Key: (2048 bit)
Modulus:
00:e7:36:7b:20:92:ba:7f:aa:a3:f6:0e:49:08:87:
f5:1c:11:33:ba:5d:f8:9b:5c:ed:c7:90:e4:f3:41:
02:06:41:f9:17:1e:52:aa:99:1a:b4:8a:5a:56:ee:
5b:ef:77:59:07:10:6e:91:6f:f7:91:61:4d:fa:30:
f5:67:49:f5:80:ad:75:54:0d:a4:dc:68:ad:e1:63:
8a:1f:59:23:b0:9e:f9:19:f6:a0:e8:7d:3b:c1:d9:

Disclosure

- **2024-04-17:** Notified CERT/CC with complete advisory
- **2024-07-24:** Public disclosure



https://kb.cert.org/vuls/id/455367

PK.FAIL Data Points

10,095 unique firmware images

8.5% vulnerable rate

791
Untrusted PK

9,304
Safe

- Users uploaded 10,095 firmware images
- Found untrusted key in 791 images (8.5%)
- Bulk of the submissions in the week after the disclosure
- Still getting on average 25 submissions per day

A closer look at the submissions

10,095 unique firmware images

8.5% vulnerable rate

791
Untrusted PK

9,304
Safe

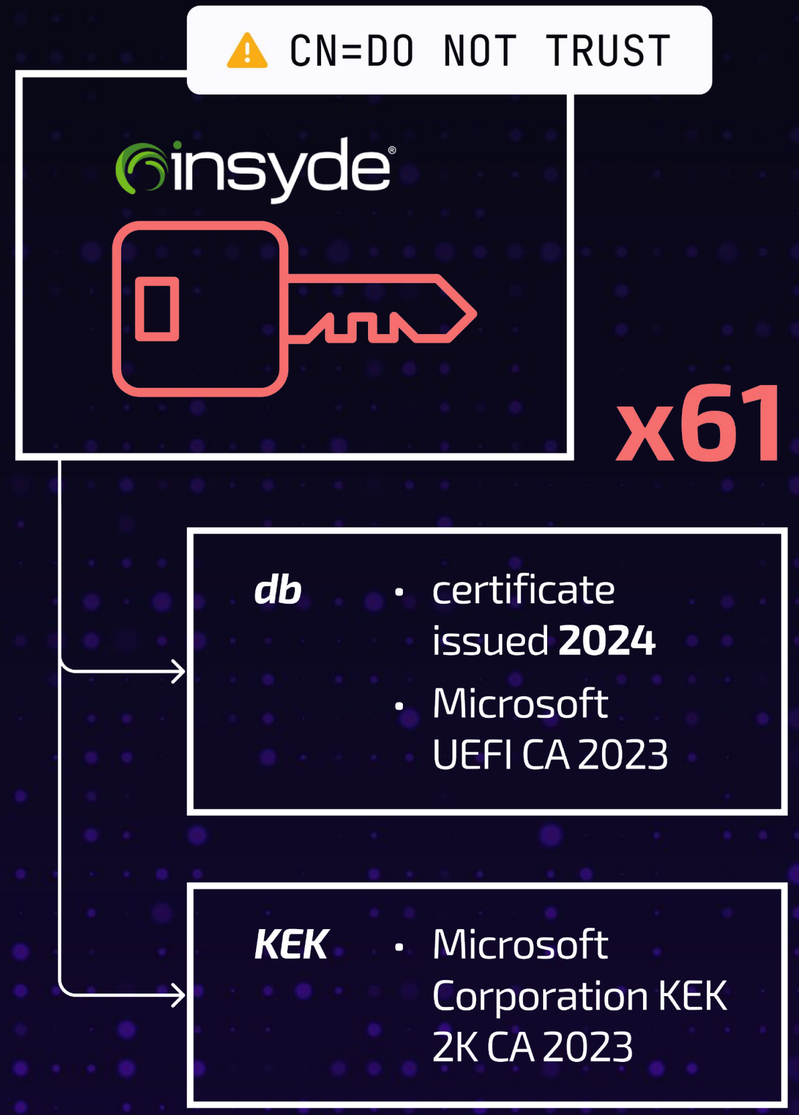
- Detected keys match results from our original research
- Four unseen keys (3 from AMI, 1 from Supermicro)
- The most common key is the one that leaked on GitHub 🔥
- Keys found on desktops, laptops, servers but also gaming consoles, ATMs, POS terminals, voting machines

A closer look at the submissions

We might have underestimated the impact for other IBVs:

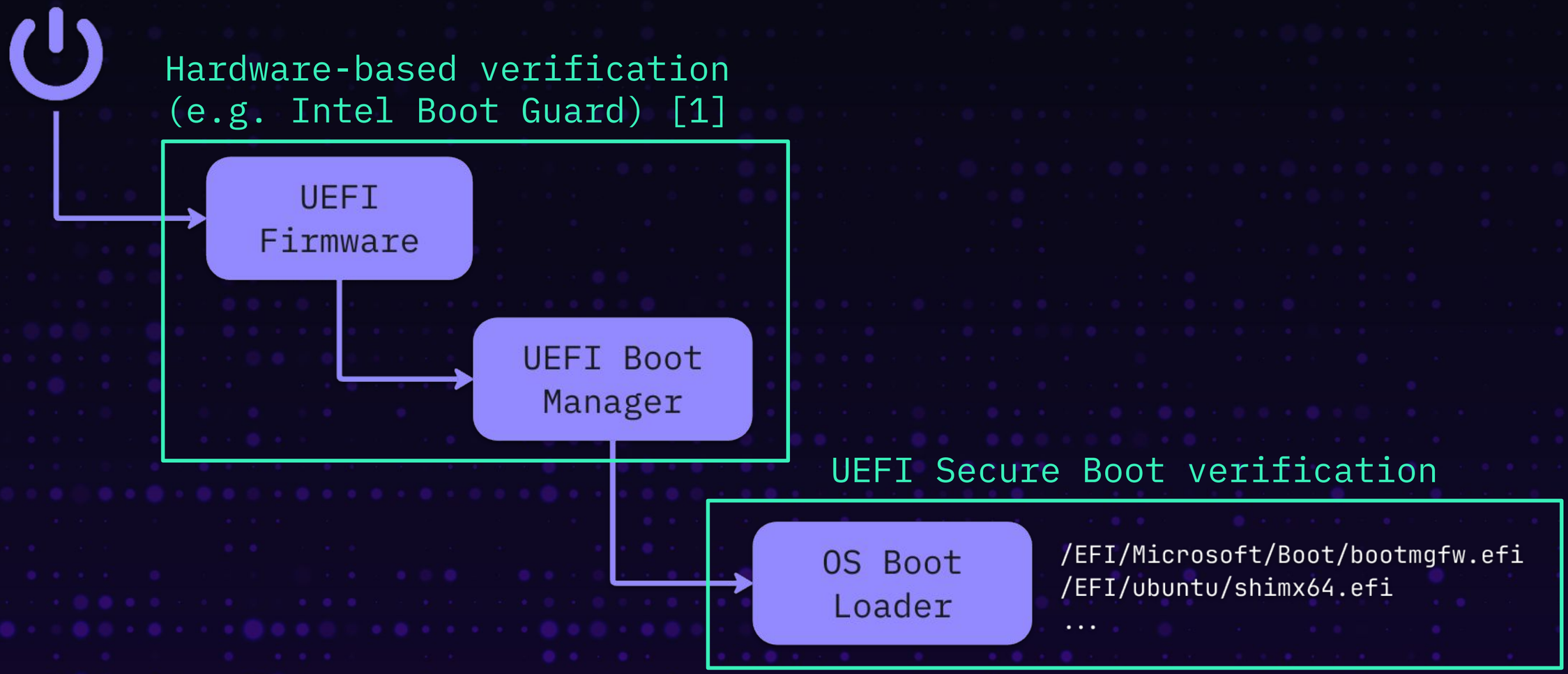
- We received 61 images with non-production key generated by Insyde
- Firmware for devices currently on the market

```
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            32:11:5d:28:e8:84:80:af:43:d5:02:fd:99:eb:bb:4b
        Signature Algorithm: sha256WithRSAEncryption
        Issuer: CN=    UEFI CA 2024, OU=      , O=            , L=San Jose, ST=California, C=US
        Validity
            Not Before: Jun 11 05:21:42 2024 GMT
            Not After : Jun 11 05:21:41 2054 GMT
        Subject: CN=    UEFI CA 2024, OU=      , O=            , L=San Jose, ST=California, C=US
```



PKfail: Exploitation and PoC Demo

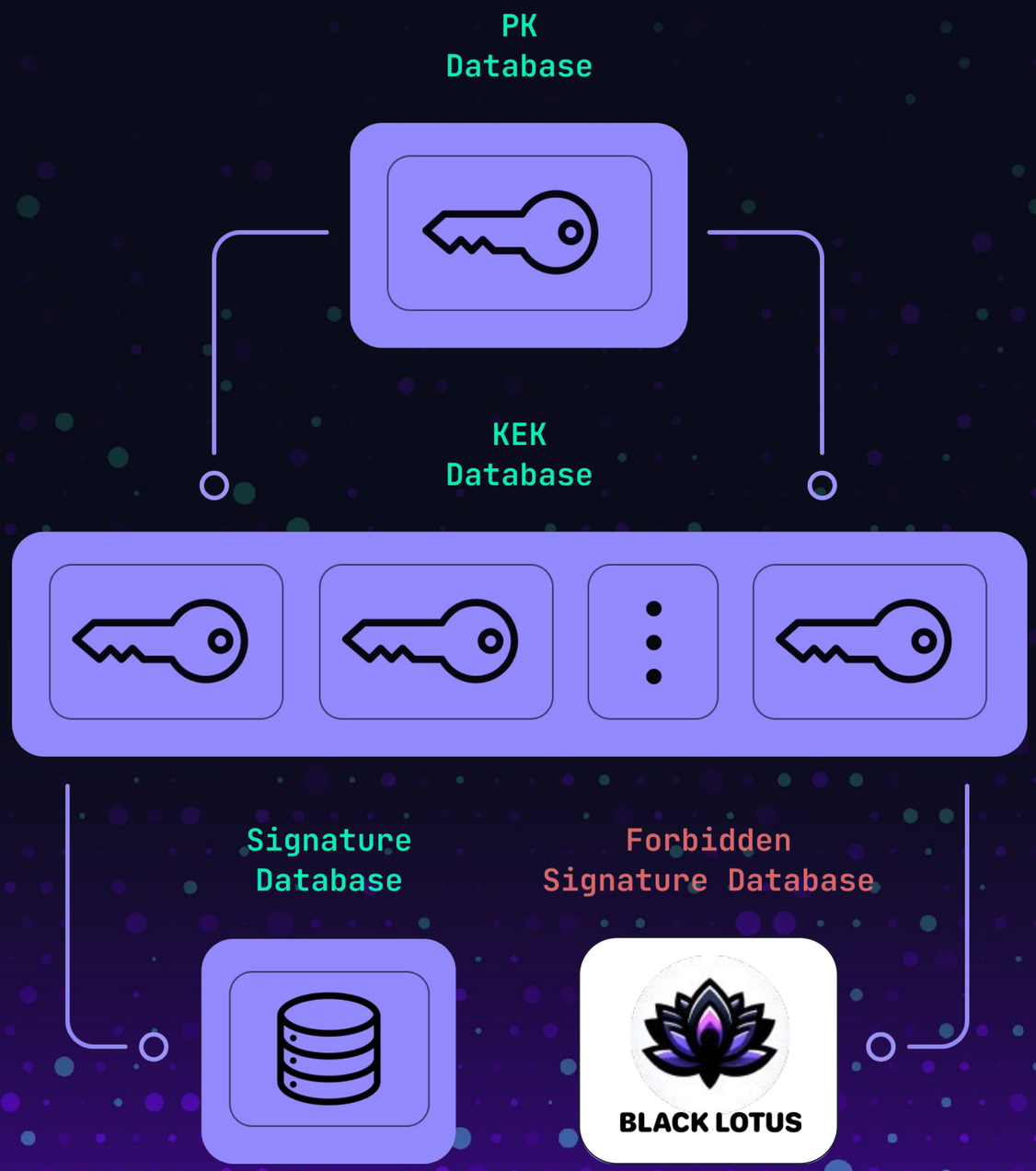
UEFI (Secure) Boot process



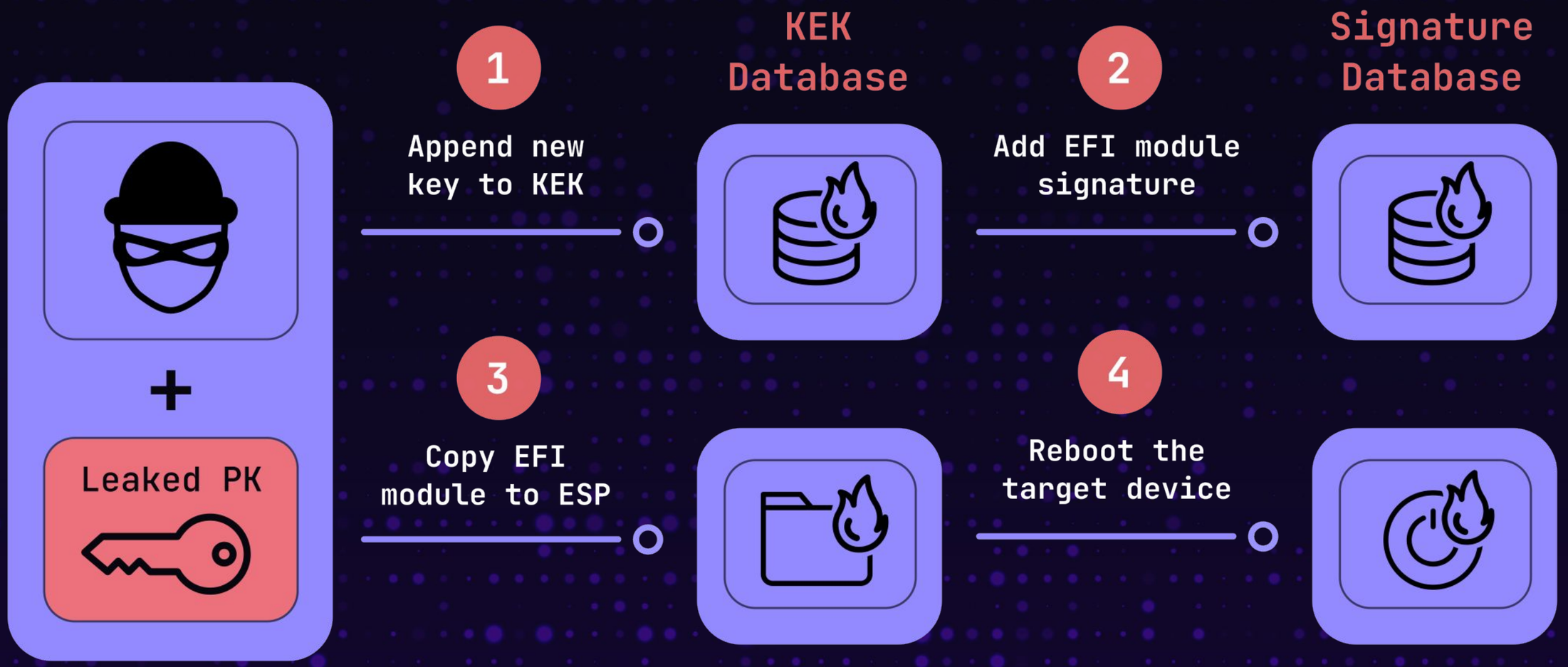
[1] **Leaked Intel Boot Guard keys: What happened? How does it affect the software supply chain? Binarly, 2022**

UEFI Secure Boot databases

1. Platform Key (PK)
2. Key Exchange Key (KEK)
3. Signature Database (db)
4. Forbidden Signature Database (dbx)



Developing a PoC



Developing a PoC

Proof of Concept for PKfail
https://www.youtube.com/watch?v=SPl7zfC-CmQ

Proof of Concept for PKfail (Linux version)
https://www.youtube.com/watch?v=CveWt3gFQTE

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Proof of Concept for PKfail

New Discovery:

Supermicro
BMC Test Key

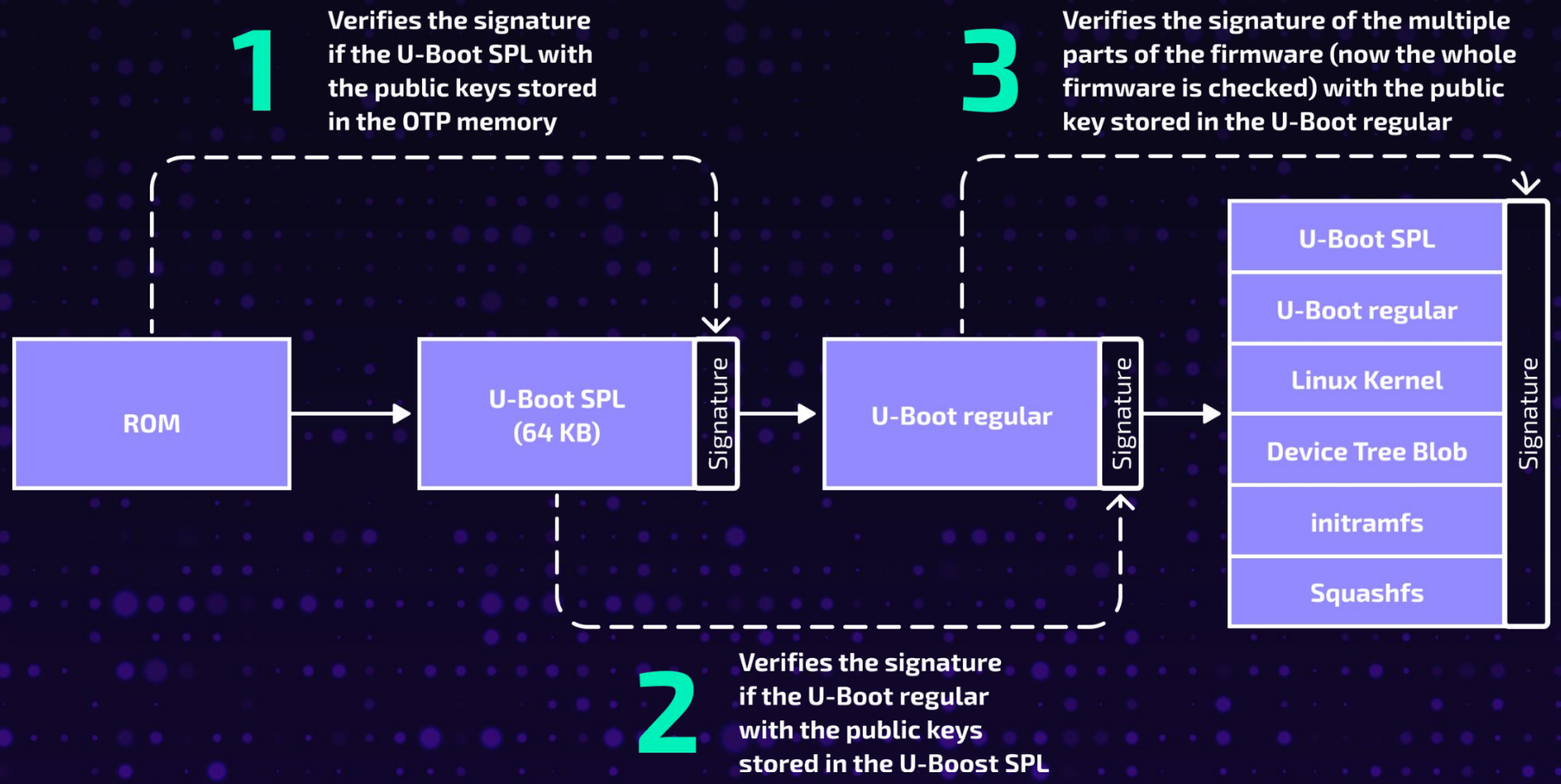
The problem is bigger than we thought…

```
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            1a:da:e6:cf:23:66:6a:36:d9:dd:69:4c:2f:ba:30:14:90:f7:3d:5e
        Signature Algorithm: sha512WithRSAEncryption
        Issuer: C = US, ST = CA, L = SanJose, O = Super Micro Computer Inc., CN = RD1 BMC Test Key - DO NOT TRUST
        Validity
            Not Before: Feb 14 03:14:28 2020 GMT
            Not After : Feb  1 03:14:28 2070 GMT
        Subject: C = US, ST = CA, L = SanJose, O = Super Micro Computer Inc., CN = RD1 BMC Test Key - DO NOT TRUST
        Subject Public Key Info:
            Public Key Algorithm: rsaEncryption
                Public-Key: (4096 bit)
                Modulus:
                    00:c6:b3:42:c9:36:c3:a1:24:0c:ec:e5:1a:31:96:
                    5b:1d:a6:c7:85:66:50:bf:59:78:9c:2d:8d:07:5e:
                    6f:9b:f0:a0:70:7a:42:f0:0a:68:bd:e1:aa:80:ef:
                    2c:70:bd:7a:36:59:6a:ca:2a:1d:21:f1:1c:a1:31:
                    f3:d6:3d:2c:ea:32:0f:d6:62:99:01:57:99:e1:13:
                    fd:82:1a:78:c7:29:2b:4c:2d:70:43:b0:c5:28:94:
```

https://www.binarly.io/blog/repeatable-failures-test-keys-used-to-sign-production-software-again

Supermicro BMC Test Key

Aspeed Root of Trust chain



https://www.binarly.io/blog/repeatable-failures-test-keys-used-to-sign-production-software-again

Supermicro Response

Production key

```
Issuer: O = "Super Micro Computer Inc. (ENG=Engineering; HSM=HSM; SB=SecureBoot)", OU = ENG, CN = R12FWSigningKey4K
Validity
    Not Before: Dec 14 01:24:22 2022 GMT
    Not After : Dec 14 01:34:20 2037 GMT
```

Test key

```
Issuer: C = US, ST = CA, L = SanJose, O = Super Micro Computer Inc., CN = RD1 BMC Test Key - DO NOT TRUST
Validity
    Not Before: Feb 14 03:14:28 2020 GMT
    Not After : Feb  1 03:14:28 2070 GMT
```

Supermicro rejected the issue:

- Test key hasn't been leaked – agree
- Test key is NIST compliant – agree
- Additional code exists in ROM, that checks the whole image with only production keys – possible
- Test key has the same access control as production key – disagree
- Test key has the same security level as production key – disagree

https://www.binarly.io/blog/repeatable-failures-test-keys-used-to-sign-production-software-again

Conclusion

- Cryptographic keys are widely reused
- Cryptographic materials not correctly stored
- Accidentally, keys are leaked sometimes
- The entire industry is impacted
- Lessons learned and will never be repeated, right?

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Thank you

https://binarly.io/pkfail

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