black hat ASIA 2019

MARCH 26-29, 2019
MARINA BAY SANDS / SINGAPORE

Finally, I Can Sleep Tonight:

Catching Sleep Mode Vulnerabilities of the TPM with Napper

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Wook Shin, Junghwan Kang, HyoungChun Kim
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Who Are We?

- Senior security researcher at NSR (National Security Research Institute of South Korea)
- Influencer Member of Black Hat Asia 2019
- Speaker at USENIX Security 2018, Black Hat Asia 2017 ~ 2019, HITBSecConf 2016 ~ 2017, BeVX 2018, and KIMCHICON 2018
- Author of “64-bit multi-core OS principles and structure, Vol.1&2”
- a.k.a kkamagui, @kkamagui1

- Senior security researcher at NSR
- Speaker at Black Hat Asia 2018 ~ 2019
- Embedded system engineer
- Interested in firmware security and IoT security
- a.k.a davepark, @davepark312

Previous Works

black hat ASIA 2018

MARCH 20–23, 2018
MARINA BAY SANDS / SINGAPORE

I Don't Want to Sleep Tonight:

Subverting Intel TXT with S3 Sleep

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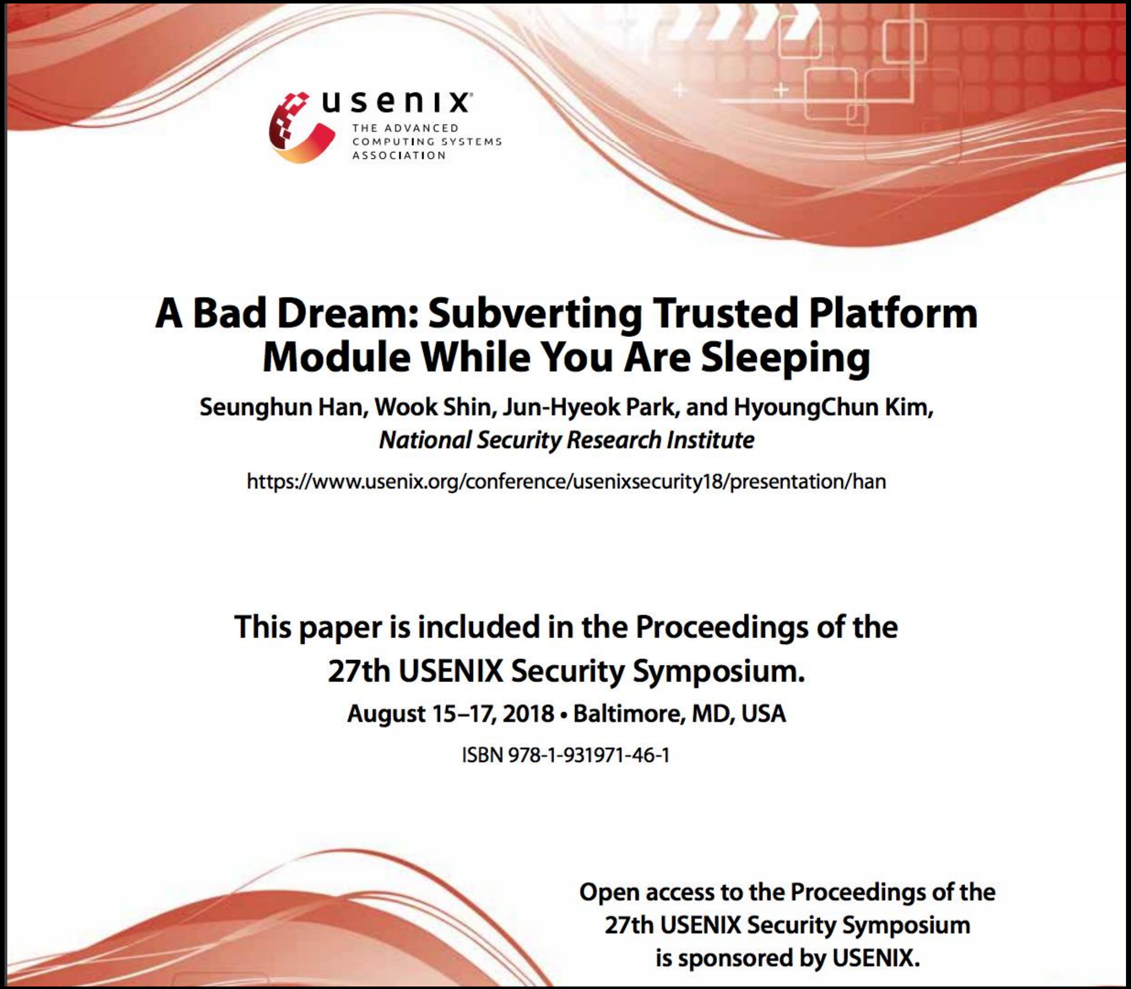
#BHASIA / @BlackHatEvents



usenix
THE ADVANCED COMPUTING SYSTEMS ASSOCIATION

A Bad Dream: Subverting Trusted Platform Module While You Are Sleeping

Seunghun Han, Wook Shin, Jun-Hyeok Park, and HyoungChun Kim,
National Security Research Institute

https://www.usenix.org/conference/usenixsecurity18/presentation/han

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Goal of This Presentation

- **We present an attack vector, “S3 Sleep” to subvert the Trusted Platform Module (TPM)**
  - S3 sleeping state cuts off the power of CPU and peripheral devices
  - We found two vulnerabilities, CVE-2017-16837 and CVE-2018-6622, that can subvert the TPM
- **We introduce new vulnerability checking tool, “Napper”**
  - Napper is a bootable USB device based on Linux
  - Napper makes your system take a nap to check the TPM vulnerability and reports the result

Everyone has a plan,
until they get punched in the mouth.

- Mike Tyson

Everyone has a plan,
until they get punched in the mouth.

- Mike Tyson

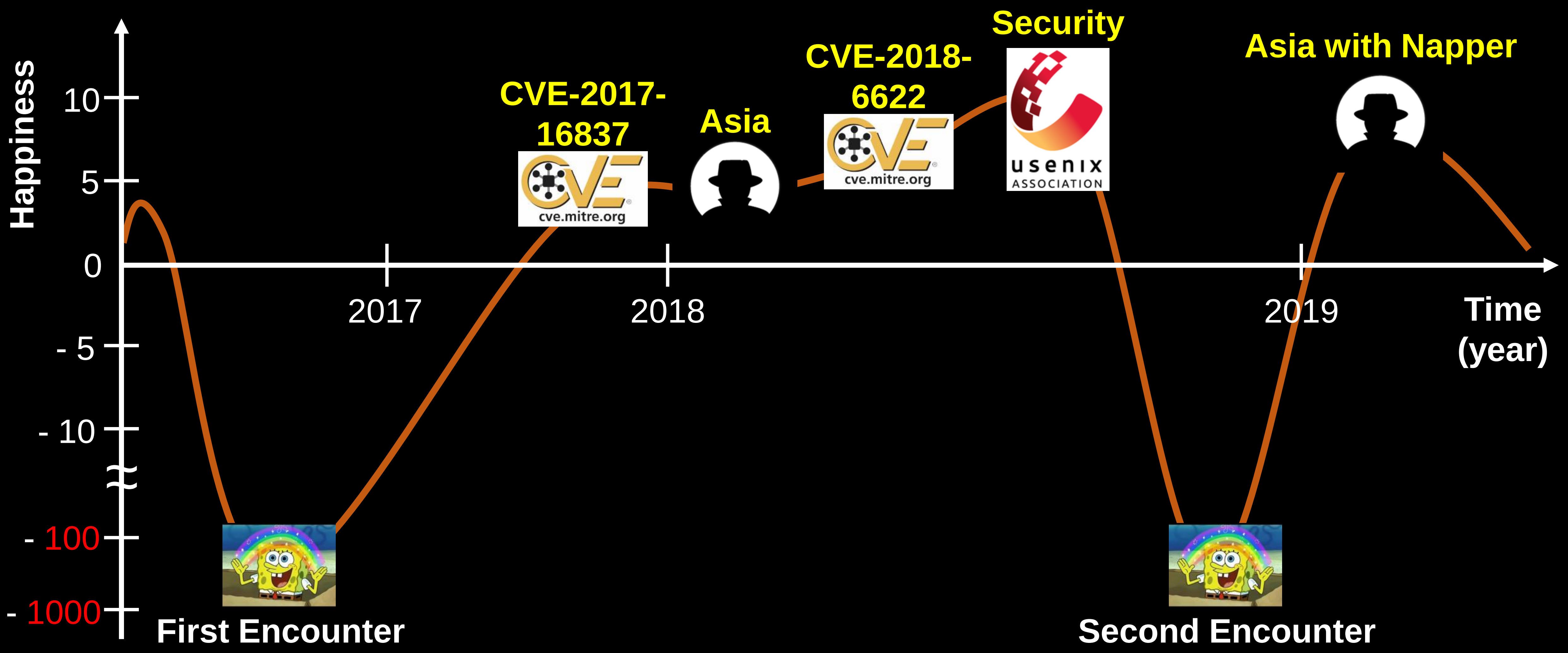
Every researcher has a plan,
until they encounter their manager.

- Unknown

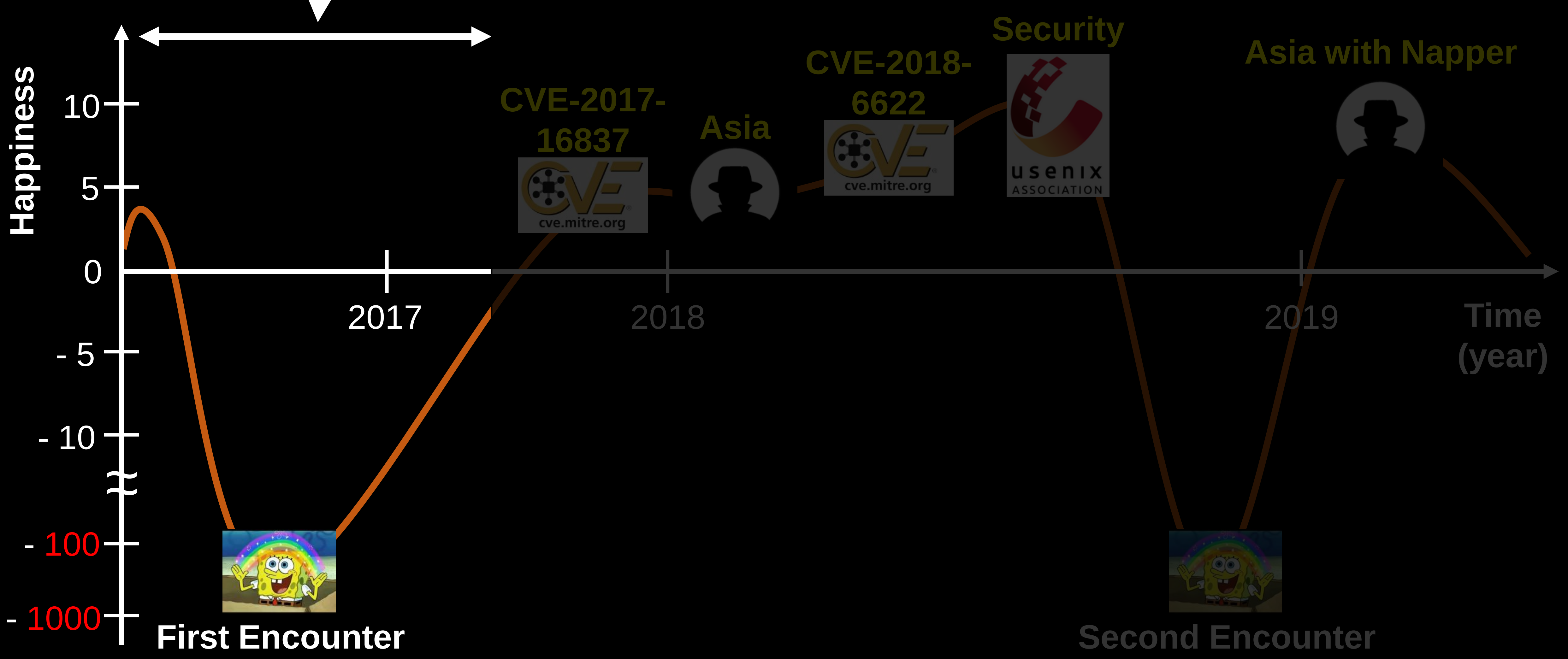
Every researcher has a plan,
until they encounter their manager.

- Unknown

Timeline


Happiness
10
5
0
- 5
- 10
- 100
- 1000
2017
2018
2019
Time (year)
CVE-2017-16837
cve.mitre.org
Asia
CVE-2018-6622
cve.mitre.org
Security
usenix ASSOCIATION
Asia with Napper
First Encounter
Second Encounter

Contents - Background



Trusted Computing Group (TCG)

- **Defines global industry specifications and standards**
    - Intel, AMD, IBM, HP, Dell, Lenovo, Microsoft, Cisco, Juniper Networks, Infineon, etc.
- **Is supportive of a hardware root of trust**
    - Trusted Platform Module (TPM) is the core technology
    - TCG technology has been applied to Unified Extensible Firmware Interface (UEFI)

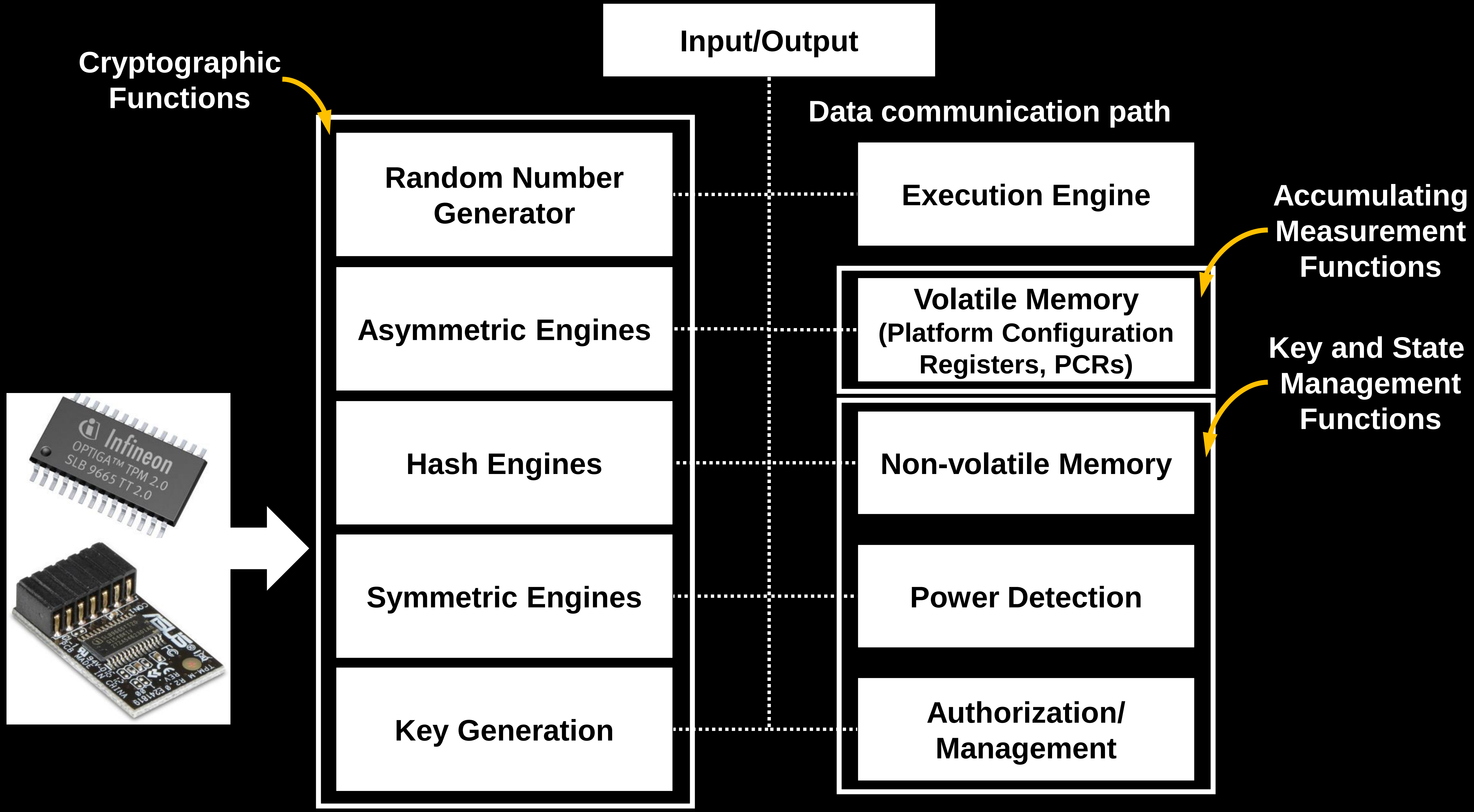
TRUSTED COMPUTING GROUP®

Trusted Computing Base (TCB) of TCG

- **Is a collection of software and hardware on a host platform**
- **Manages and enforces a security policy of the system**
- **Is able to prevent itself from being compromised**
  - The Trusted Platform Module (TPM) helps to ensure that the TCB is properly instantiated and trustworthy

Trusted Platform Module (TPM) (1)

- Is a tamper-resistant device
- Has own processor, RAM, ROM, and non-volatile RAM
  - It has own state separated from the system
- Provides cryptographic and accumulating measurements functions
  - Measurement values are accumulated to Platform Configuration Registers (PCR #0~#23)



Input/Output

Data communication path

Cryptographic Functions

Random Number Generator

Asymmetric Engines

Hash Engines

Symmetric Engines

Key Generation

Execution Engine

Accumulating Measurement Functions

Volatile Memory (Platform Configuration Registers, PCRs)

Key and State Management Functions

Non-volatile Memory

Power Detection

Authorization/ Management

Architecture Overview of TPM

Trusted Platform Module (TPM) (2)

- **Is used to determine the trustworthiness of a system by investigating the values stored in PCRs**
  - A local verification or remote attestation can be used
- **Is used to limit access to secret data based on specific PCR values**
  - “Seal” operation encrypts secret data with the PCRs of the TPM
  - “Unseal” operation can decrypt the sealed data only if the PCR values match the specific values

Root of Trust for Measurement (RTM)

- Sends integrity-relevant information (measurements) to the TPM
  - TPM accumulates the measurements to a PCR with the previously stored value in the PCR

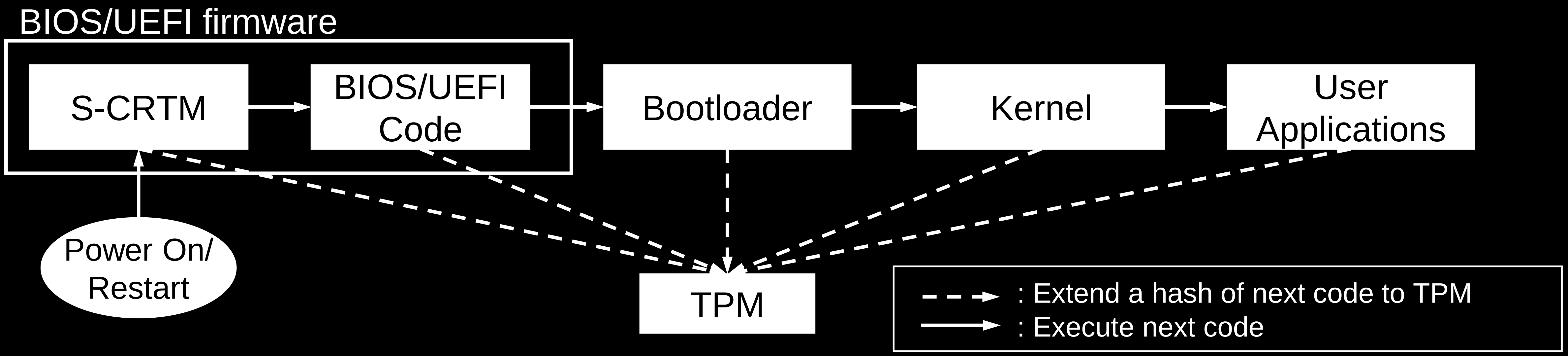
Extend: $PCR_{new} = Hash(PCR_{old} \,||\, Measurement_{new})$

- Is the CPU controlled by Core RTM (CRTM)
  - The CRTM is the first set of instructions when a new chain of trust is established

Static and Dynamic RTM (SRTM and DRTM)

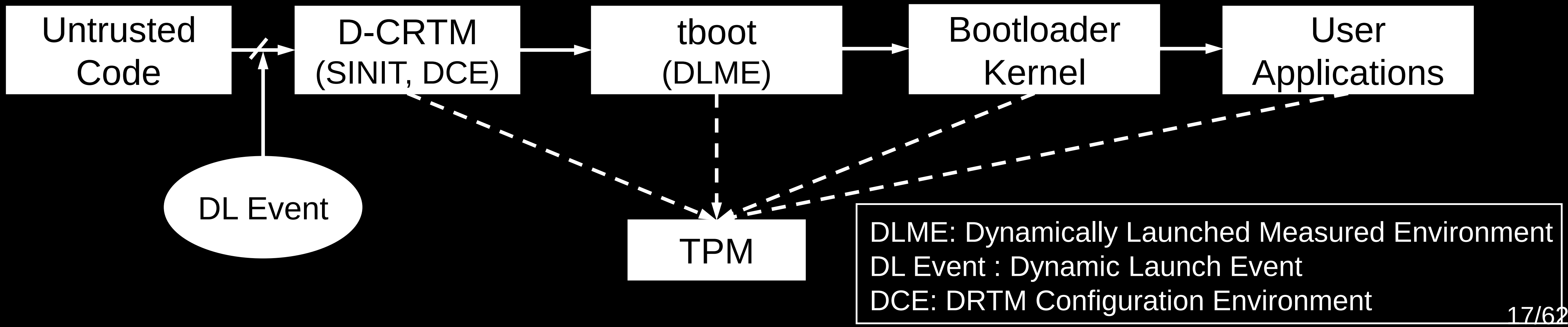
- SRTM is started by static CRTM (S-CRTM) when the host platform starts at POWER-ON or RESTART
- DRTM is started by dynamic CRTM (D-CRTM) at runtime WITHOUT platform RESET
- They extend measurements (hashes) of components to PCRs BEFORE passing control to them

Static Root of Trust for Measurement (SRTM)



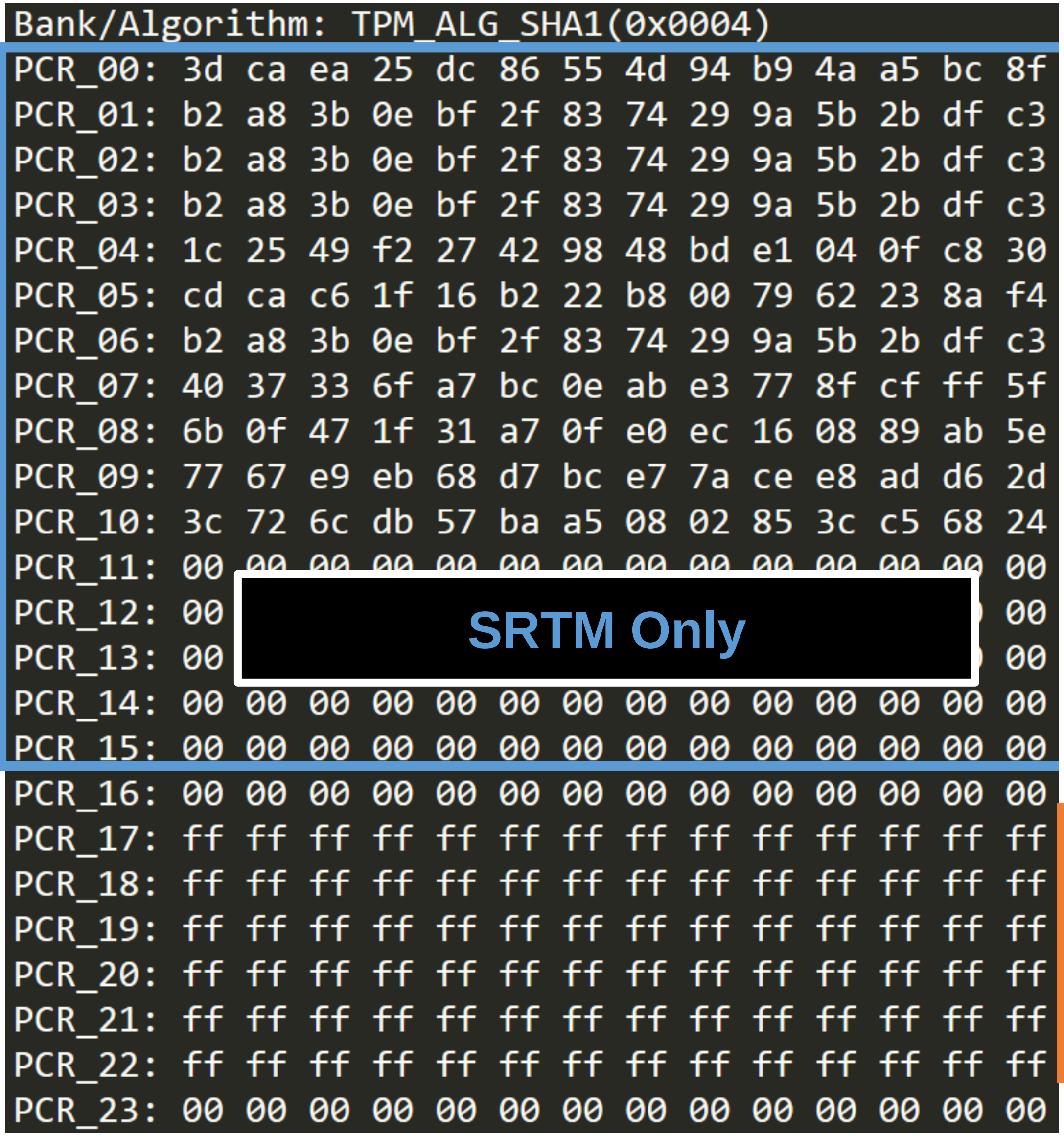
Dynamic Root of Trust for Measurement (DRTM)

(Intel Trusted Execution Technology)



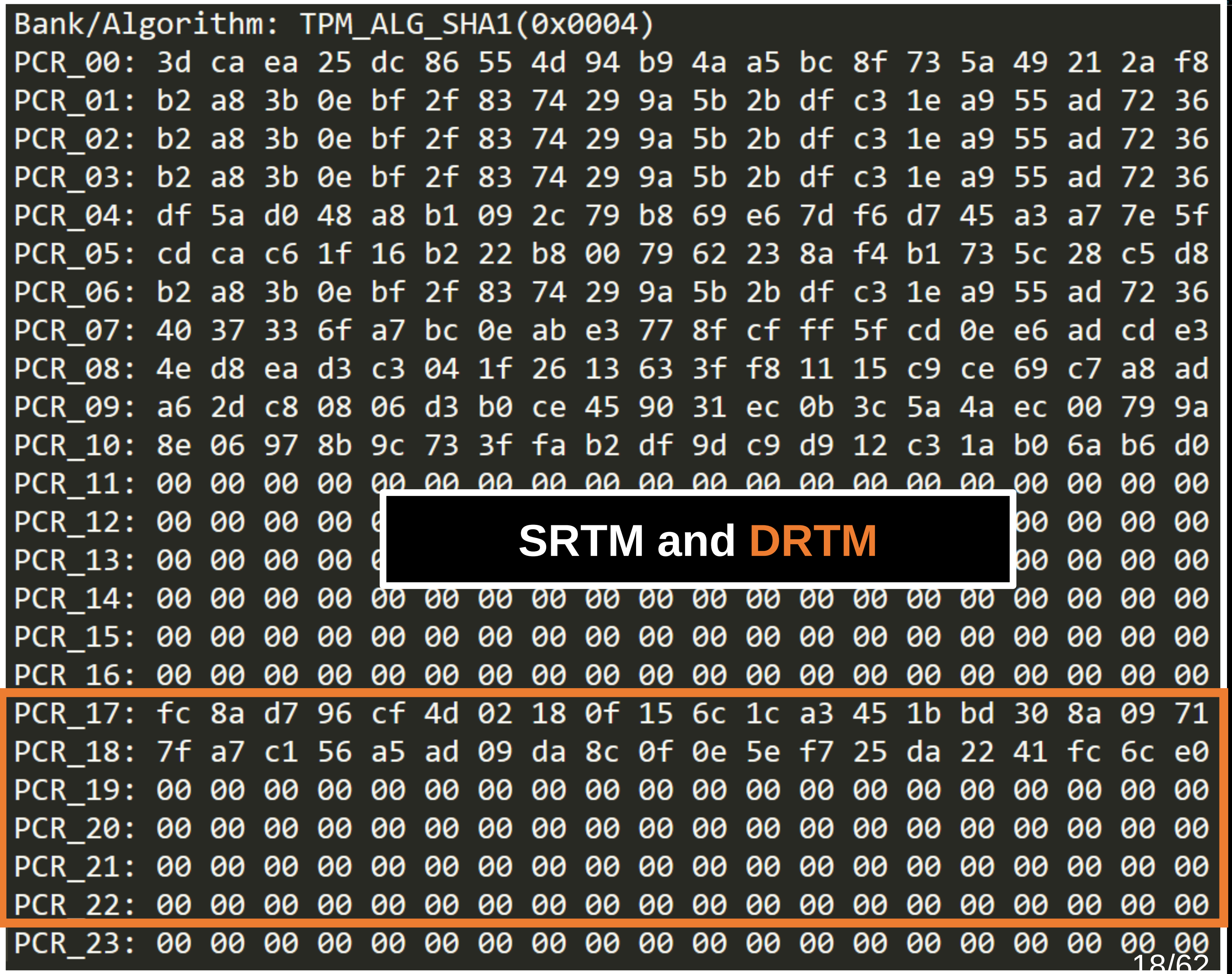
DLME: Dynamically Launched Measured Environment
DL Event : Dynamic Launch Event
DCE: DRTM Configuration Environment

examples of PCR values



```
Bank/Algorithm: TPM_ALG_SHA1(0x0004)
PCR_00: 3d ca ea 25 dc 86 55 4d 94 b9 4a a5 bc 8f
PCR_01: b2 a8 3b 0e bf 2f 83 74 29 9a 5b 2b df c3
PCR_02: b2 a8 3b 0e bf 2f 83 74 29 9a 5b 2b df c3
PCR_03: b2 a8 3b 0e bf 2f 83 74 29 9a 5b 2b df c3
PCR_04: 1c 25 49 f2 27 42 98 48 bd e1 04 0f c8 30
PCR_05: cd ca c6 1f 16 b2 22 b8 00 79 62 23 8a f4
PCR_06: b2 a8 3b 0e bf 2f 83 74 29 9a 5b 2b df c3
PCR_07: 40 37 33 6f a7 bc 0e ab e3 77 8f cf ff 5f
PCR_08: 6b 0f 47 1f 31 a7 0f e0 ec 16 08 89 ab 5e
PCR_09: 77 67 e9 eb 68 d7 bc e7 7a ce e8 ad d6 2d
PCR_10: 3c 72 6c db 57 ba a5 08 02 85 3c c5 68 24
PCR_11: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_12: 00                                     00
PCR_13: 00                                     00
PCR_14: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_15: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_16: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_17: ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_18: ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_19: ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_20: ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_21: ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_22: ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_23: 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

SRTM Only



```
Bank/Algorithm: TPM_ALG_SHA1(0x0004)
PCR_00: 3d ca ea 25 dc 86 55 4d 94 b9 4a a5 bc 8f 73 5a 49 21 2a f8
PCR_01: b2 a8 3b 0e bf 2f 83 74 29 9a 5b 2b df c3 1e a9 55 ad 72 36
PCR_02: b2 a8 3b 0e bf 2f 83 74 29 9a 5b 2b df c3 1e a9 55 ad 72 36
PCR_03: b2 a8 3b 0e bf 2f 83 74 29 9a 5b 2b df c3 1e a9 55 ad 72 36
PCR_04: df 5a d0 48 a8 b1 09 2c 79 b8 69 e6 7d f6 d7 45 a3 a7 7e 5f
PCR_05: cd ca c6 1f 16 b2 22 b8 00 79 62 23 8a f4 b1 73 5c 28 c5 d8
PCR_06: b2 a8 3b 0e bf 2f 83 74 29 9a 5b 2b df c3 1e a9 55 ad 72 36
PCR_07: 40 37 33 6f a7 bc 0e ab e3 77 8f cf ff 5f cd 0e e6 ad cd e3
PCR_08: 4e d8 ea d3 c3 04 1f 26 13 63 3f f8 11 15 c9 ce 69 c7 a8 ad
PCR_09: a6 2d c8 08 06 d3 b0 ce 45 90 31 ec 0b 3c 5a 4a ec 00 79 9a
PCR_10: 8e 06 97 8b 9c 73 3f fa b2 df 9d c9 d9 12 c3 1a b0 6a b6 d0
PCR_11: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_12: 00 00 00 00 0                                  00 00 00 00
PCR_13: 00 00 00 00 0                                  00 00 00 00
PCR_14: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_15: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_16: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_17: fc 8a d7 96 cf 4d 02 18 0f 15 6c 1c a3 45 1b bd 30 8a 09 71
PCR_18: 7f a7 c1 56 a5 ad 09 da 8c 0f 0e 5e f7 25 da 22 41 fc 6c e0
PCR_19: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_20: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_21: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_22: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_23: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

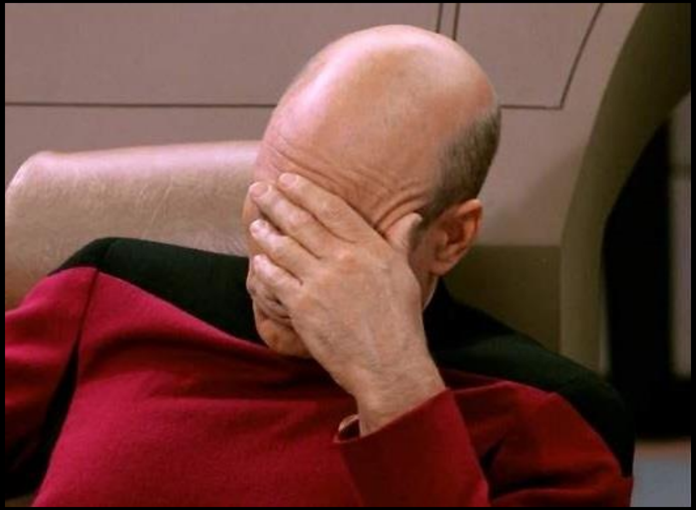
SRTM and DRTM

PCR Protection

- **They MUST NOT be reset by disallowed operations even though an attacker gains a root privilege!**
  - Static PCRs (PCR #0~#15) can be reset only if the host resets
  - Dynamic PCRs (PCR #17~#22) can be reset only if the host initializes the DRTM
- **If PCRs are reset by attackers, they can reproduce specific PCR values by replaying hashes**
  - They can steal the secret and deceive the local and remote verification

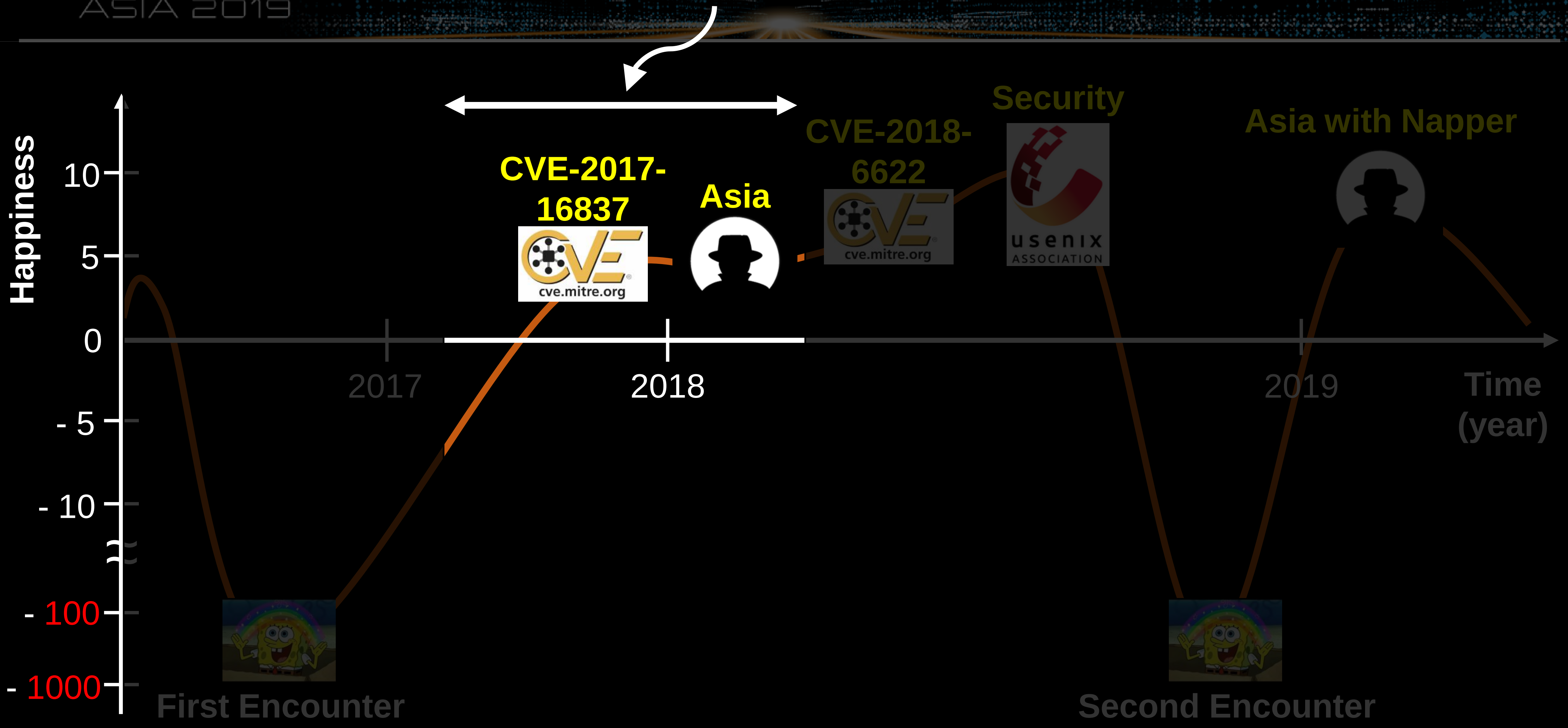
PCR protection mechanisms work properly

UNTIL WE PUBLISHED THE VULNERABILITIES!



OH... NO...

Contents - CVE-2017-16837



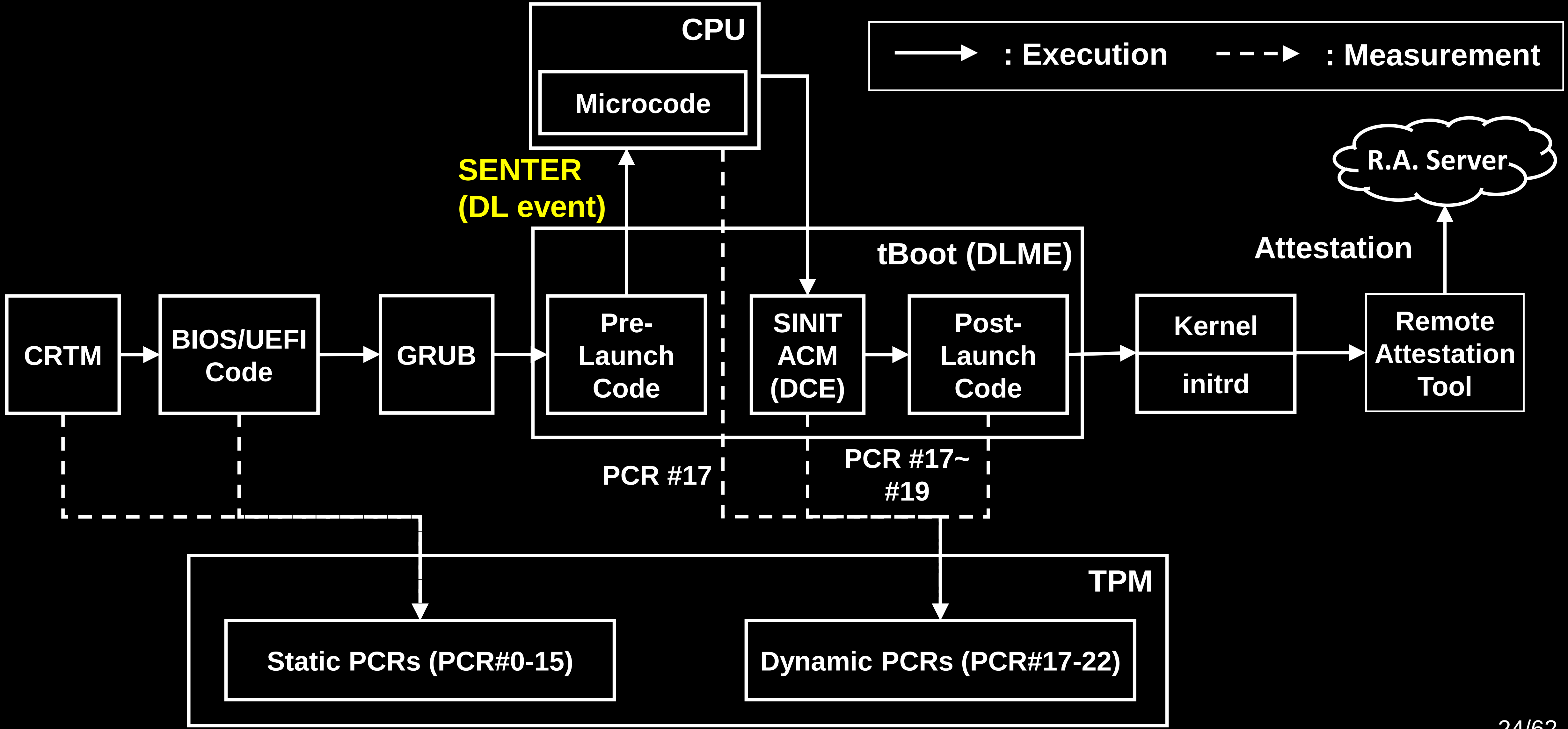
Intel Trusted Execution Environment (TXT)

- **Is the DRTM technology of TCG specification**
  - Intel just uses their own terminologies
  - ex) DCE = Secure Initialization Authenticated Code Module (SINIT ACM)
    DLME = Measured Launched Environment (MLE)
- **Has a special command (SENTER and SEXIT) to enter trustworthy state and exit from it**
  - SENTER checks if SINIT ACM has a valid signature
  - Intel publishes SINIT ACM on the website

Trusted Boot (tBoot)

- **Is a reference implementation of Intel TXT**
  - It is an open source project (https://sourceforge.net/projects/tboot/)
  - It has been included many Linux distros such as RedHat, SUSE, and Ubuntu
- **Can verify OS and Virtual Machine Monitor (VMM)**
  - It measures OS components and stores hashes to the TPM
  - Measured results in PCRs of the TPM can be verified by remote attestation server such as Intel Open CIT
  - It is typically used in server environments

Boot Process of tBoot



Boot process is (maybe) perfect!

How about sleep process?

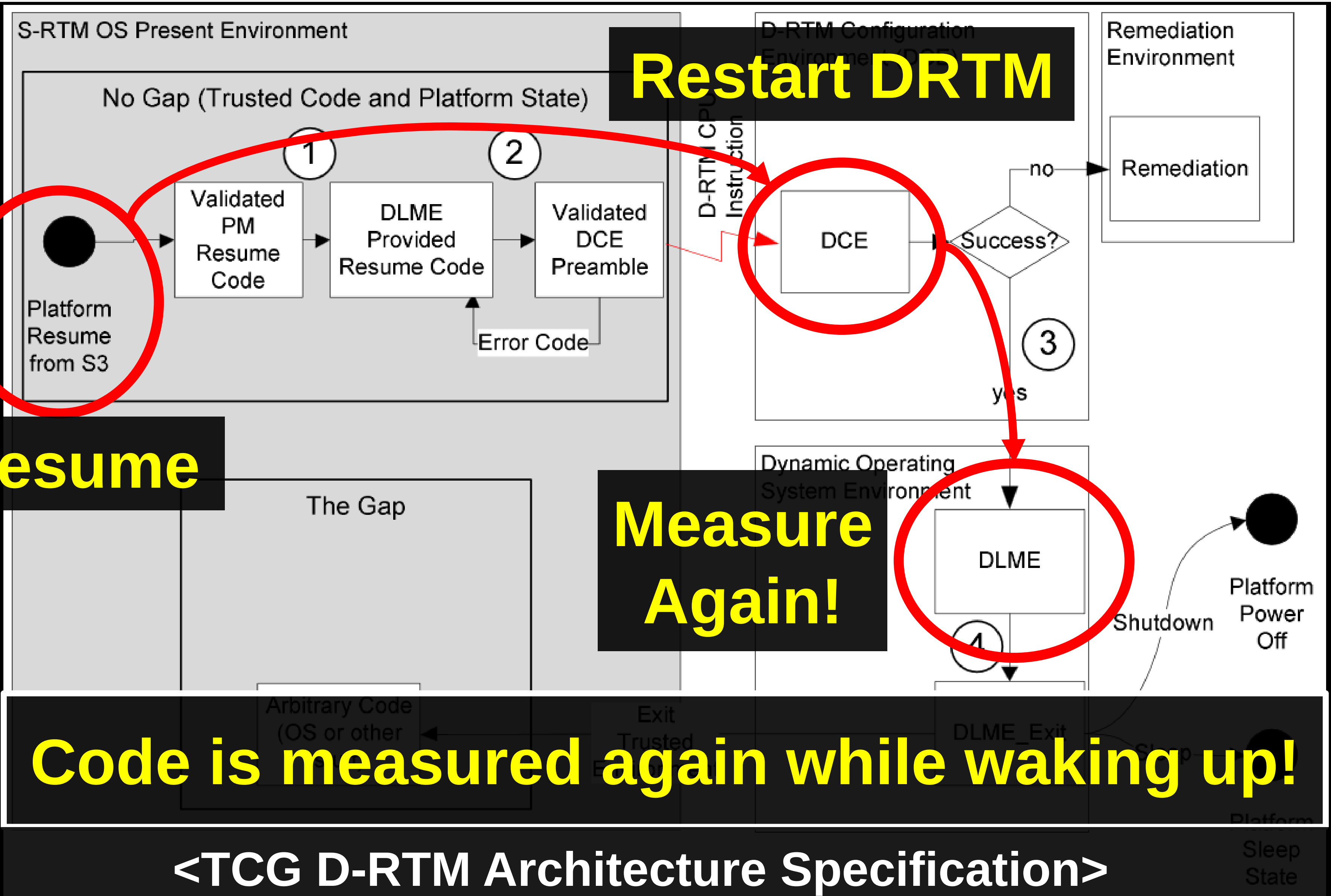
Advanced Configuration and Power Interface (ACPI) and Sleeping States

- Cut off the power of…

- S0: Normal, no context is lost
- S1: Standby, the CPU cache is lost
- S2: Standby, the **CPU** is **POWERED OFF**
- S3: Suspend, **CPU and devices** are **POWERED OFF**
- S4: Hibernate, the **CPU, devices, and RAM** are **POWERED OFF**
- S5: Soft Off, all parts are **POWERED OFF**

TPM is also POWERED OFF!

Waking Up Process of the DRTM



Restart DRTM

Resume

Measure Again!

Code is measured again while waking up!

<TCG D-RTM Architecture Specification>

Sleep Process with tBoot

Seal S3 key and MAC of Kernel Memory with Post-Launch PCRs

- seal_post_k_state() → g_tpm->seal()

Save Static PCRs(0~16)

- tpm->save_state()

Shutdown Intel TXT

- txt_shutdown()

Sleep. Power off the CPU and the TPM!

- shutdown_system()

Wake Up, Restore Static PCRs, and Resume tBoot

- Real Mode, Single CPU

Launch MLE again and then, Unseal S3 key and MAC with P-Launch PCRs

- begin_launch() → txt_s3_launch_environment()
- post_launch() → s3_launch() → verify_integrity() → g_tpm->unseal()

Extend PCRs and Resume Kernel

- verify_integrity() → extends_pcrs() → **g_tpm→extend()**
- s3_launch()->_prot_to_real()

Sleep Process with tBoot

Seal S3 key and MAC of Kernel Memory with Post-Launch PCRs

- seal_post_k_state() → g_tpm->seal()

Save Static PCRs(0~16)

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Sleep. Power off the CPU and the TPM

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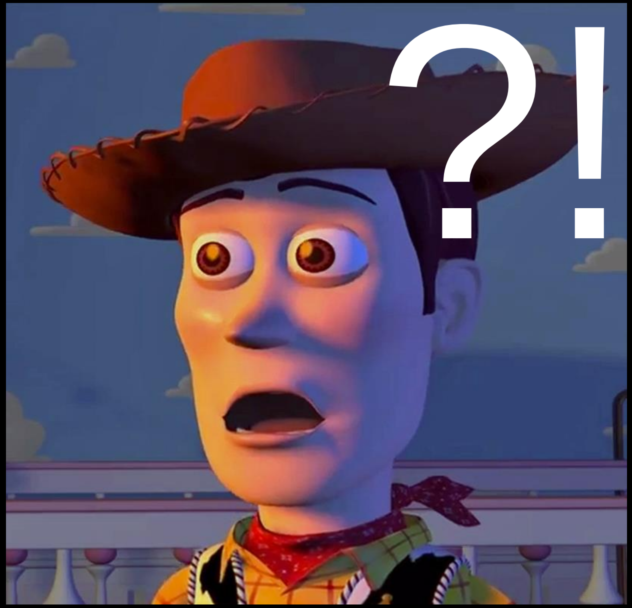

Wake Up, Restore Static PCRs, and Re

- Real Mode, Single CPU

Launch MLE again and then, Unseal S3 n PCRs

- begin_launch() → txt_s3_launch_environment()
- post_launch() → s3_launch() → verify_integrity() → g_tpm->unseal()

Extend PCRs and Resume Kernel

- verify_integrity() → extends_pcrs() → **g_tpm→extend()**
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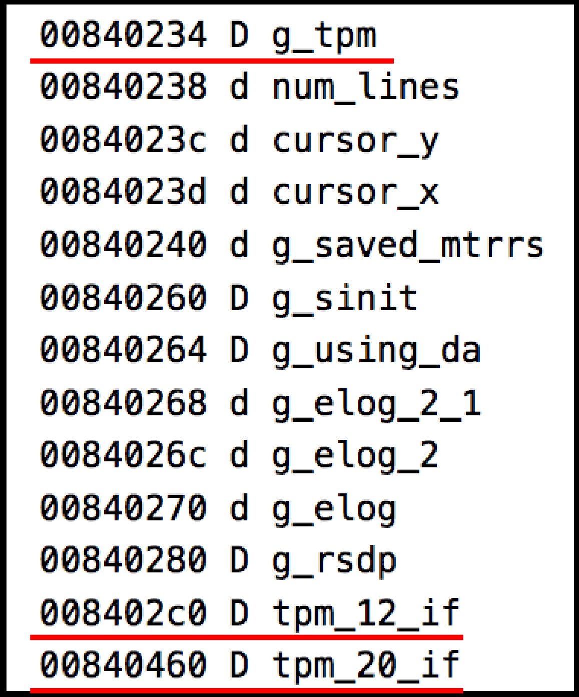
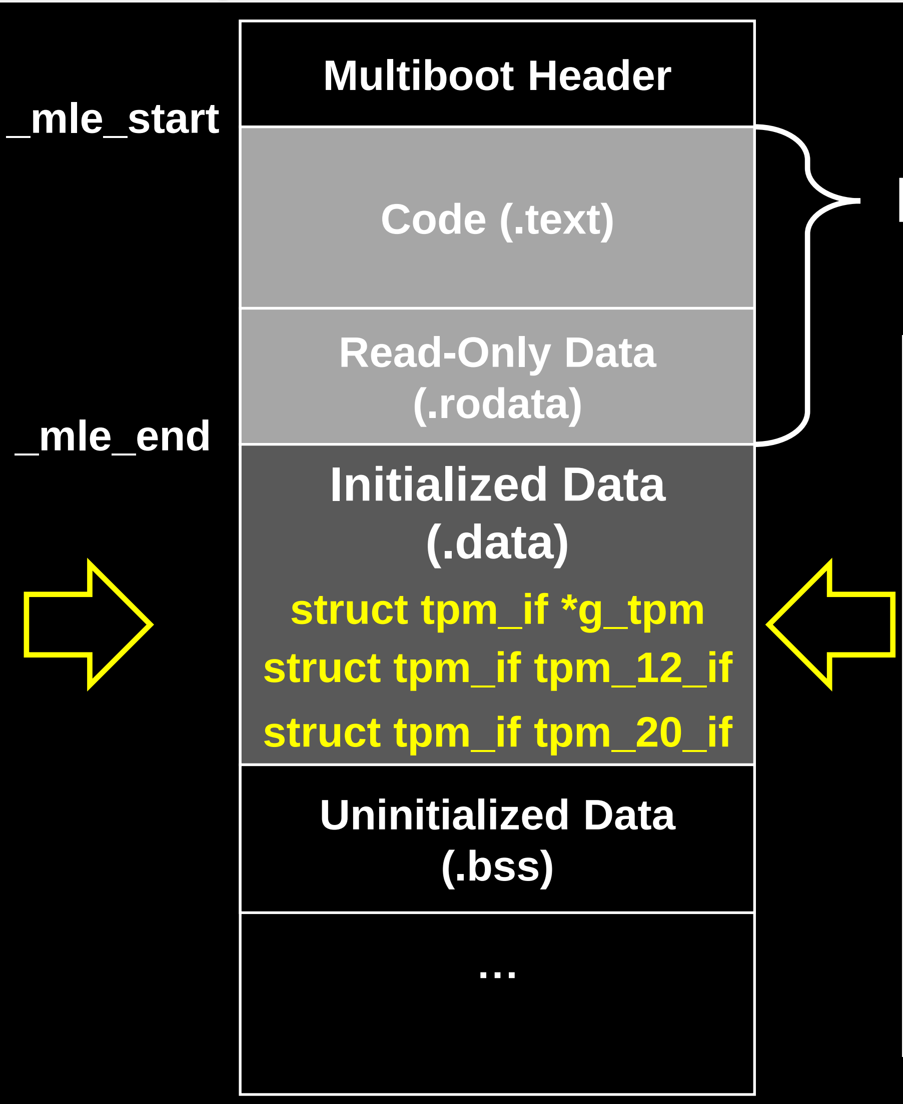
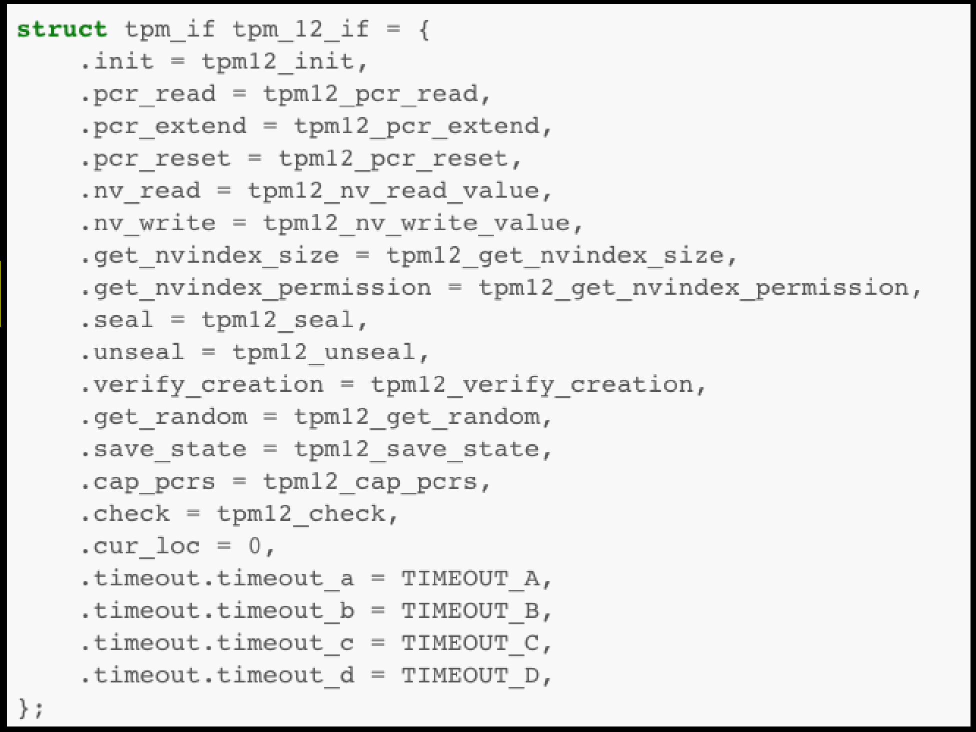
“Lost Pointer” Vulnerability (CVE-2017-16837)



```
00840234 D g_tpm
00840238 d num_lines
0084023c d cursor_y
0084023d d cursor_x
00840240 d g_saved_mtrrs
00840260 D g_sinit
00840264 D g_using_da
00840268 d g_elog_2_1
0084026c d g_elog_2
00840270 d g_elog
00840280 D g_rsdp
008402c0 D tpm_12_if
00840460 D tpm_20_if
```



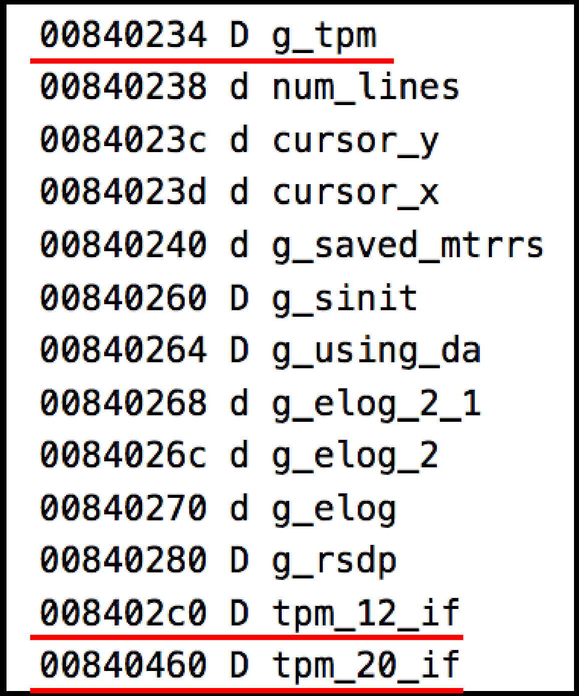
Measured by Intel TXT!



```
struct tpm_if tpm_12_if = {
    .init = tpm12_init,
    .pcr_read = tpm12_pcr_read,
    .pcr_extend = tpm12_pcr_extend,
    .pcr_reset = tpm12_pcr_reset,
    .nv_read = tpm12_nv_read_value,
    .nv_write = tpm12_nv_write_value,
    .get_nvindex_size = tpm12_get_nvindex_size,
    .get_nvindex_permission = tpm12_get_nvindex_permission,
    .seal = tpm12_seal,
    .unseal = tpm12_unseal,
    .verify_creation = tpm12_verify_creation,
    .get_random = tpm12_get_random,
    .save_state = tpm12_save_state,
    .cap_pcrs = tpm12_cap_pcrs,
    .check = tpm12_check,
    .cur_loc = 0,
    .timeout.timeout_a = TIMEOUT_A,
    .timeout.timeout_b = TIMEOUT_B,
    .timeout.timeout_c = TIMEOUT_C,
    .timeout.timeout_d = TIMEOUT_D,
};
```

Memory Layout of tBoot

“Lost Pointer” Vulnerability (CVE-2017-16837)



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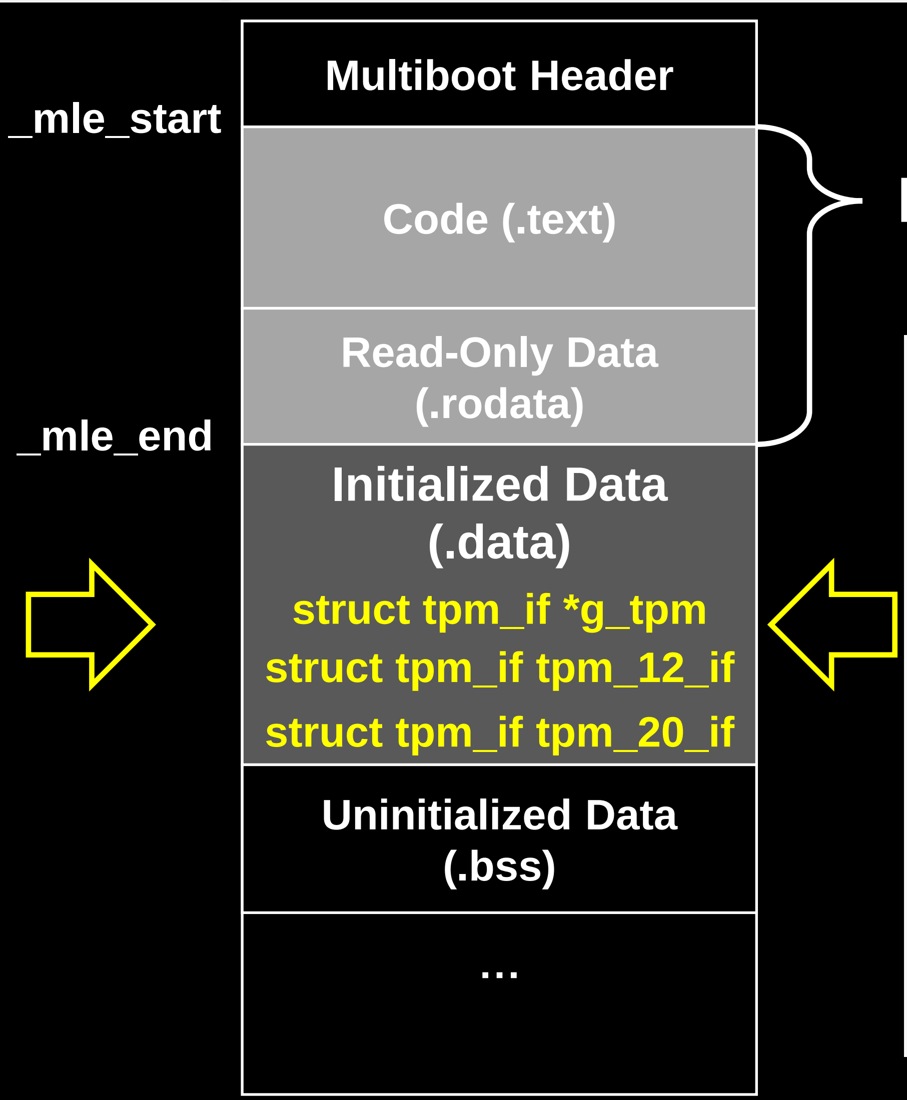
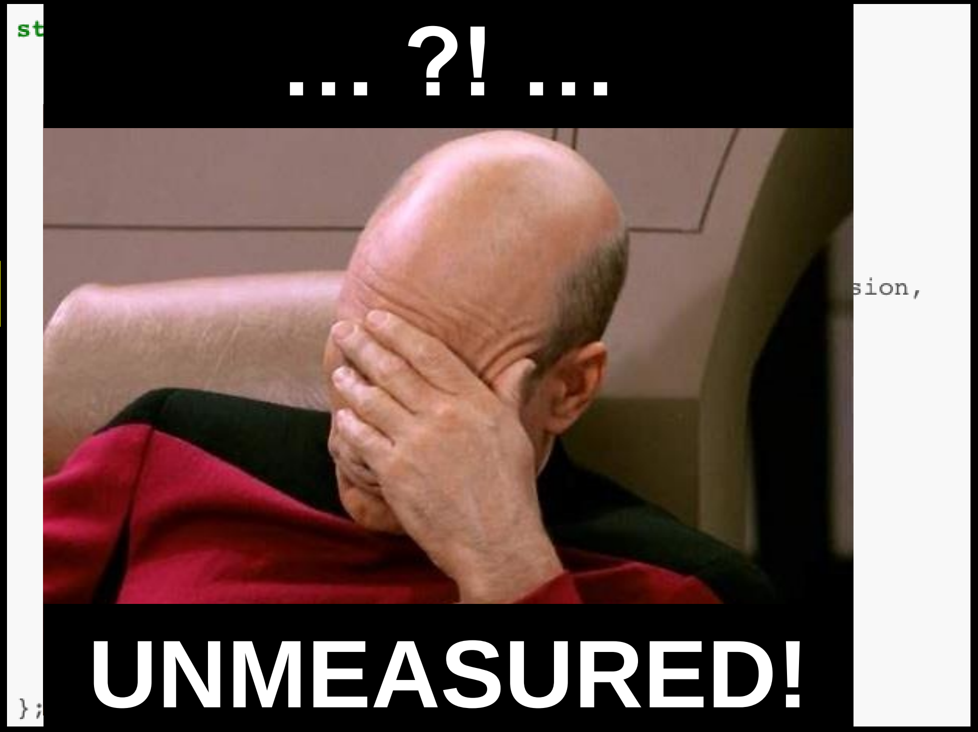
0084023d d cursor_x
00840240 d g_saved_mtrrs
00840260 D g_sinit
00840264 D g_using_da
00840268 d g_elog_2_1
0084026c d g_elog_2
00840270 d g_elog
00840280 D g_rsdp
008402c0 D tpm_12_if
00840460 D tpm_20_if
```

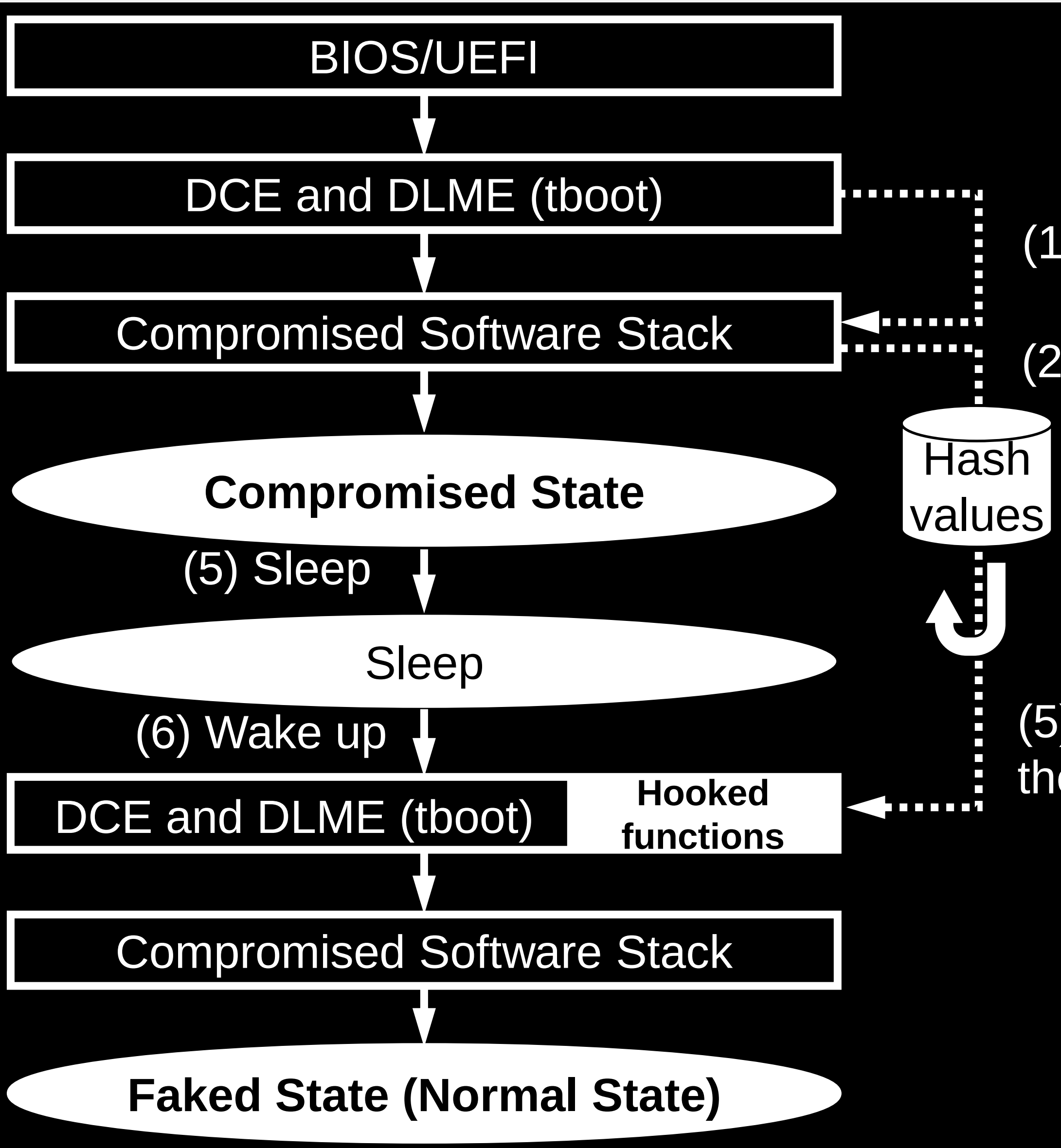


Measured by Intel TXT!

Memory Layout of tBoot



Exploit Scenario of the CVE-2017-16837 (1)



(1) Leave normal hashes in event logs

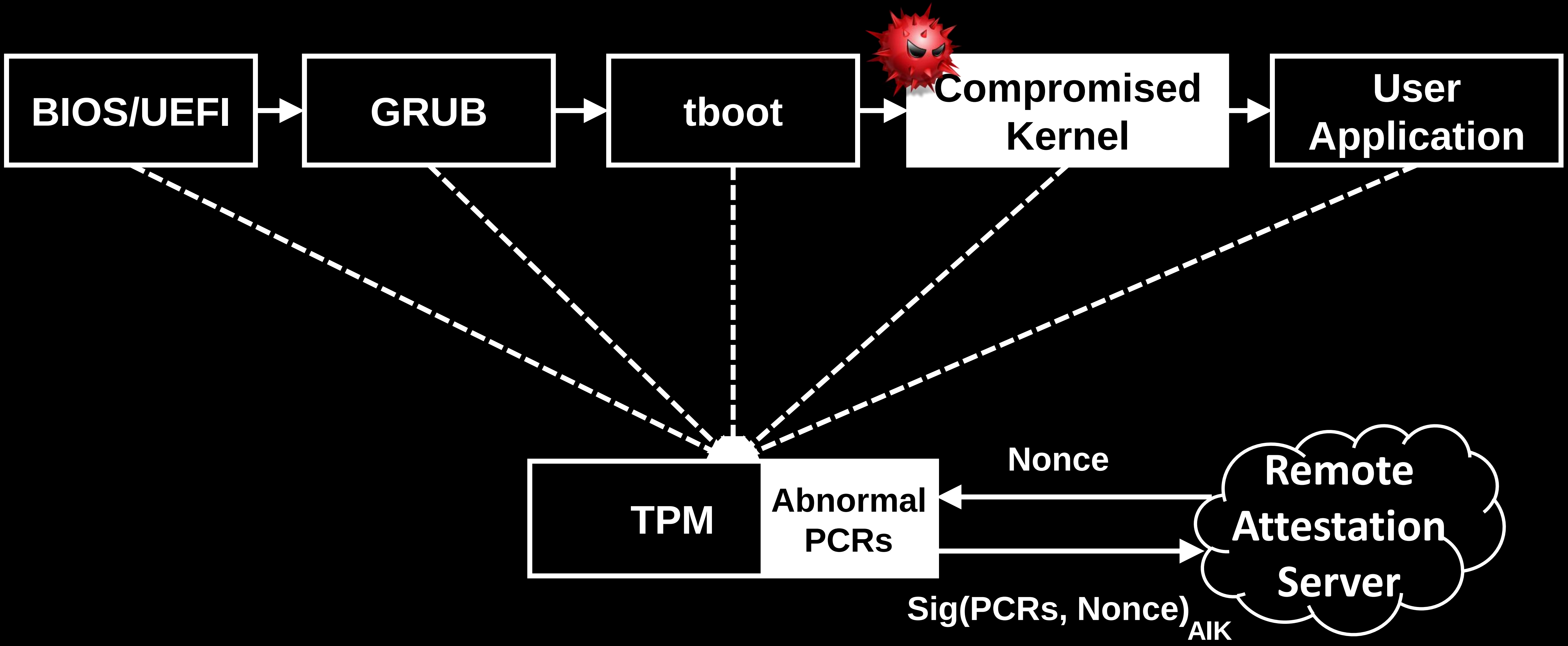
(2) Extract and calculate the normal hashes

(3) Store the normal hashes in RAM

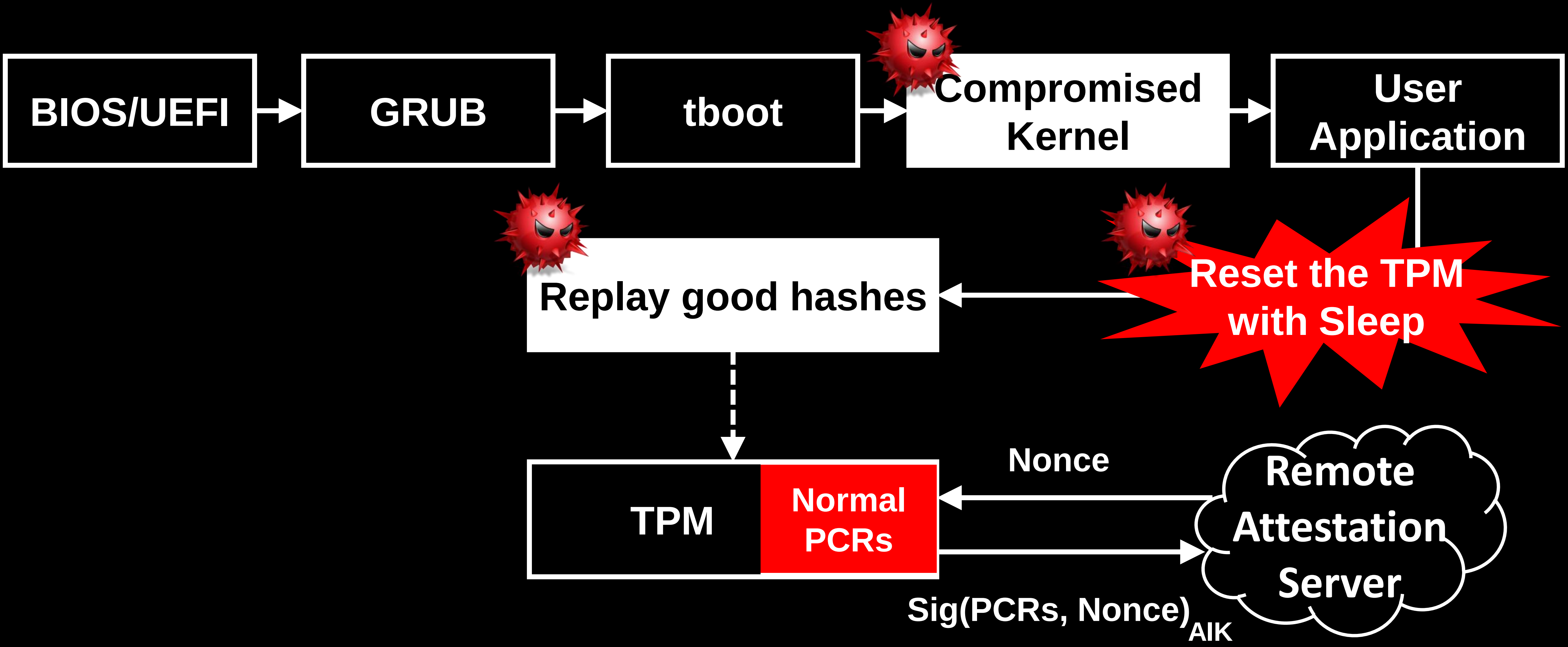
(4) Hook function pointers in the DCE and the DLME

(5) Reset the TPM and replay the normal hashes with the hooked functions

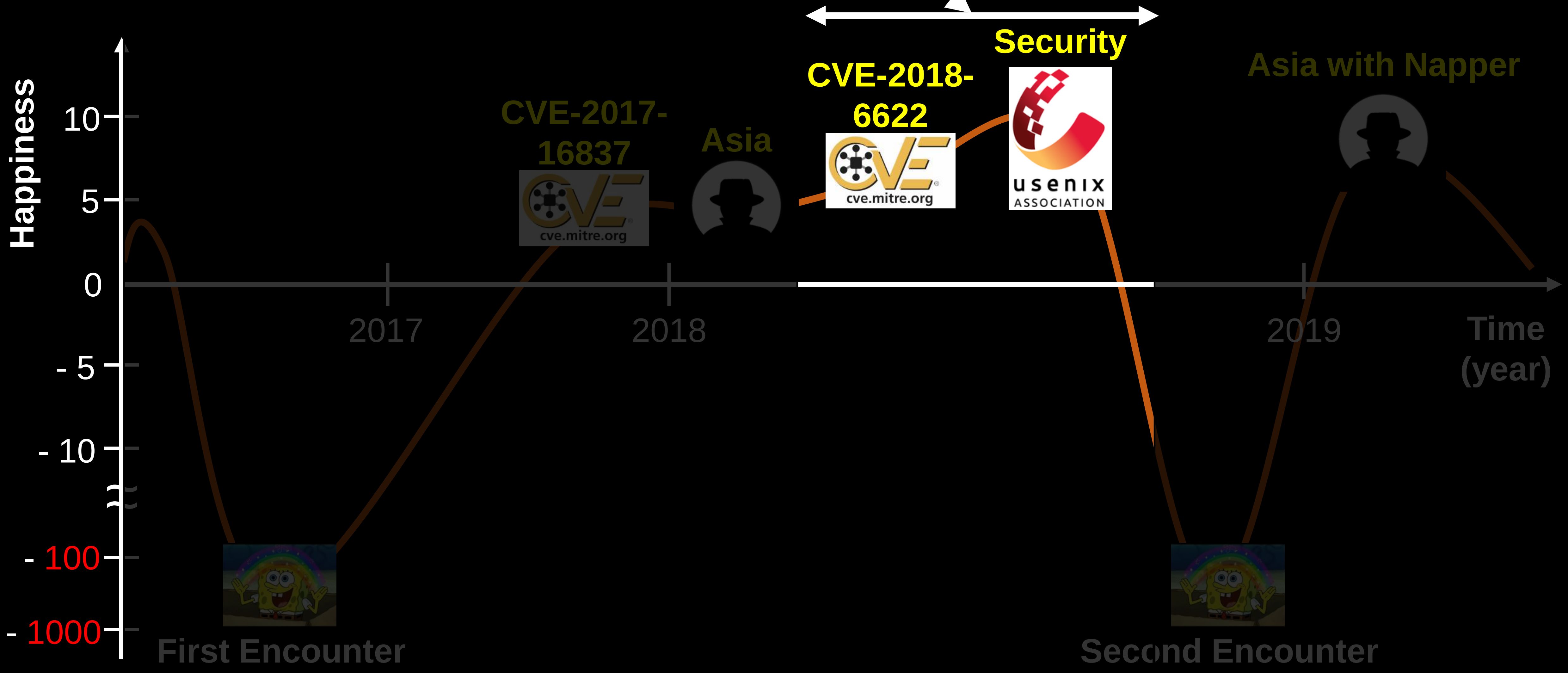
Exploit Scenario of the CVE-2017-16837 (2)



Exploit Scenario of the CVE-2017-16837 (3)



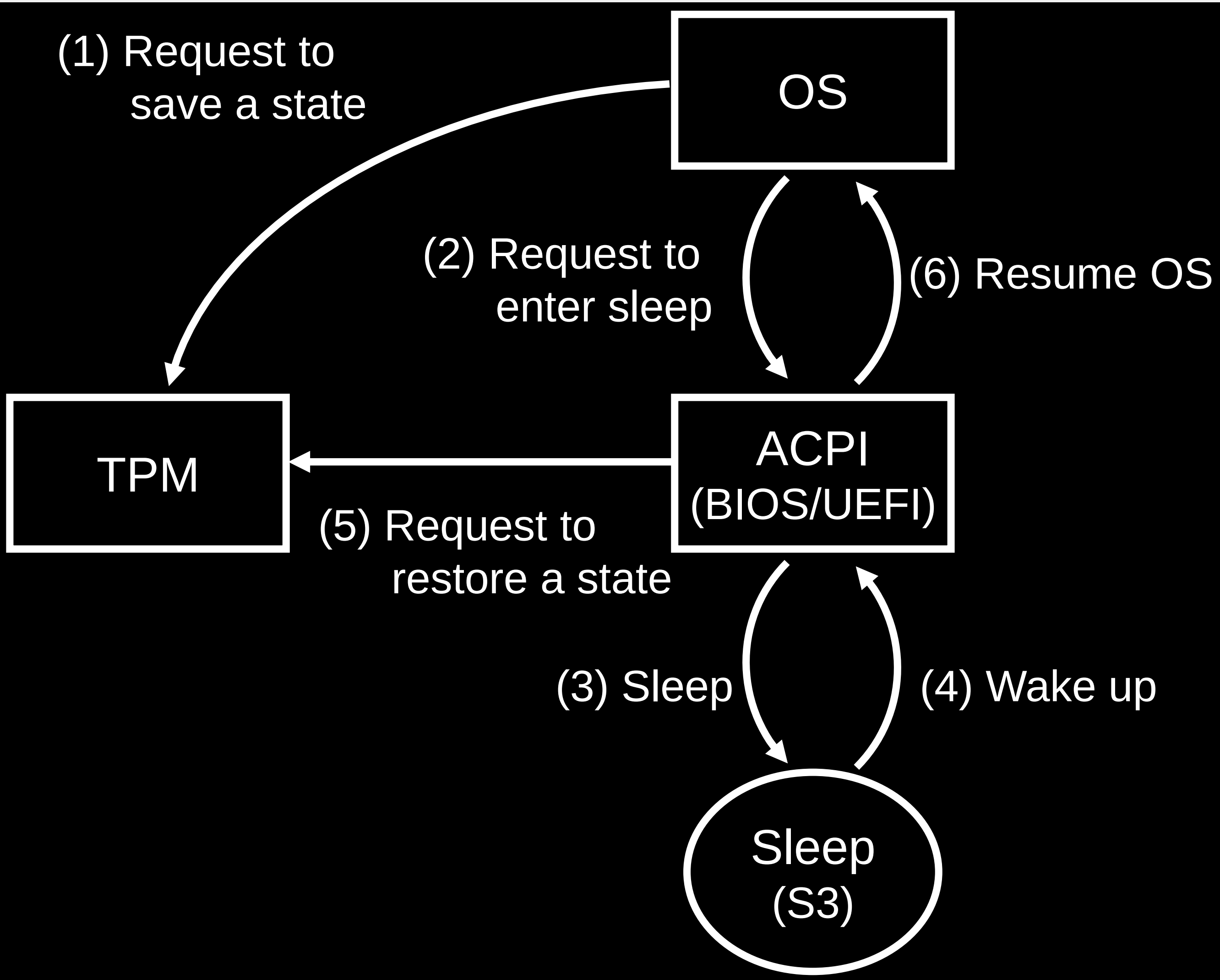
Contents - CVE-2018-6622



DRTM measures code while waking up!

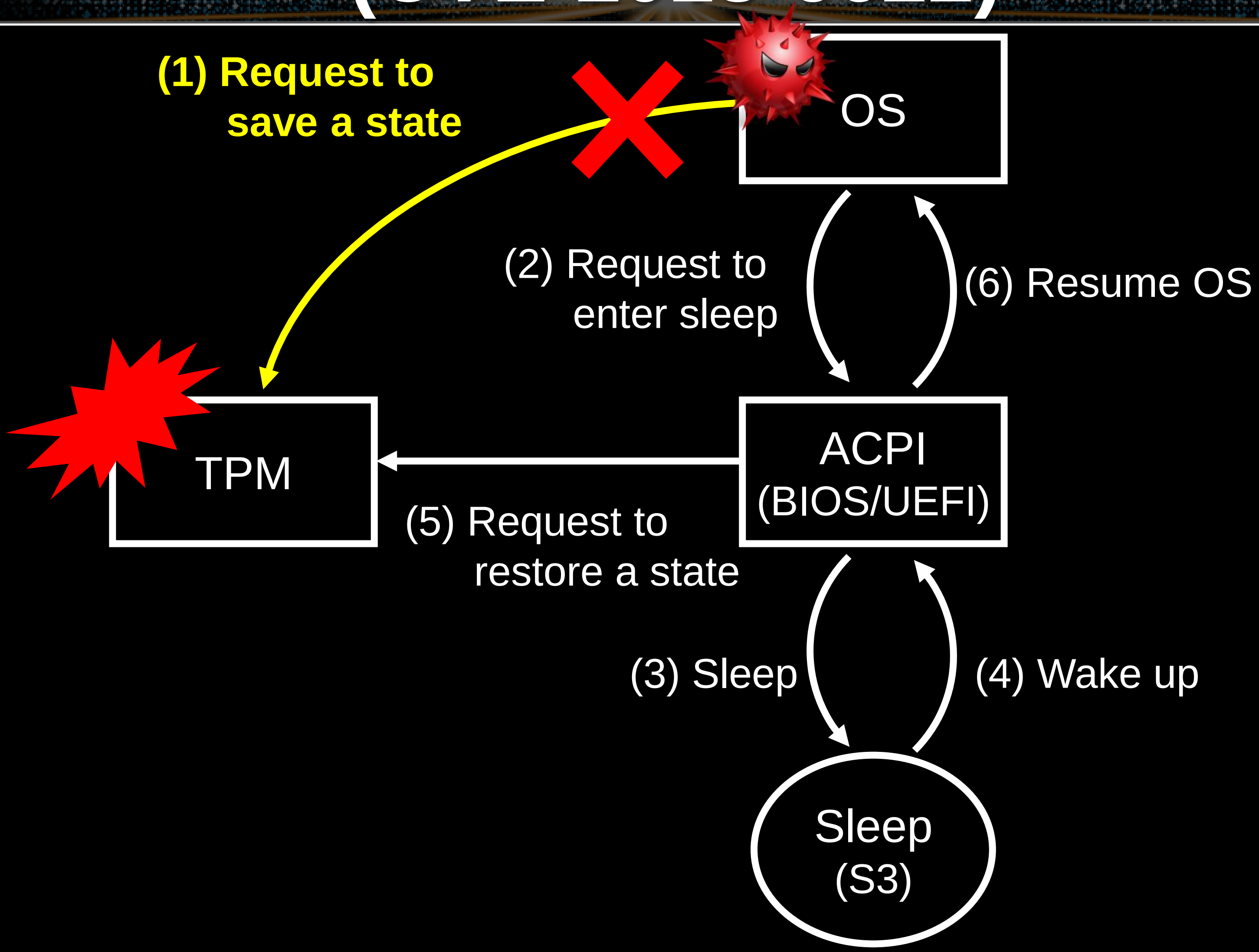
How about SRTM?

Waking Up Process of the SRTM


(1) Request to save a state
OS
(2) Request to enter sleep
(6) Resume OS
TPM
ACPI (BIOS/UEFI)
(5) Request to restore a state
(3) Sleep
(4) Wake up
Sleep (S3)

<TCG PC Client Platform Firmware Profile Specification>

"Grey Area" Vulnerability (1) (CVE-2018-6622)

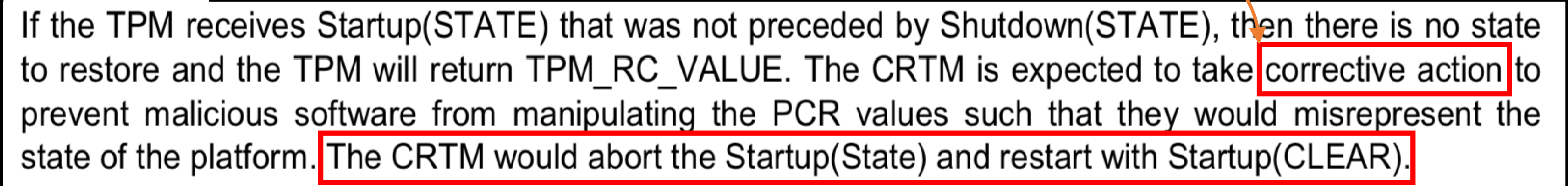

(1) Request to save a state
OS
(2) Request to enter sleep
(6) Resume OS
TPM
ACPI (BIOS/UEFI)
(5) Request to restore a state
(3) Sleep
(4) Wake up
Sleep (S3)

<TCG PC Client Platform Firmware Profile Specification>

“Grey Area” Vulnerability (2) (CVE-2018-6622)

TPM 2.0

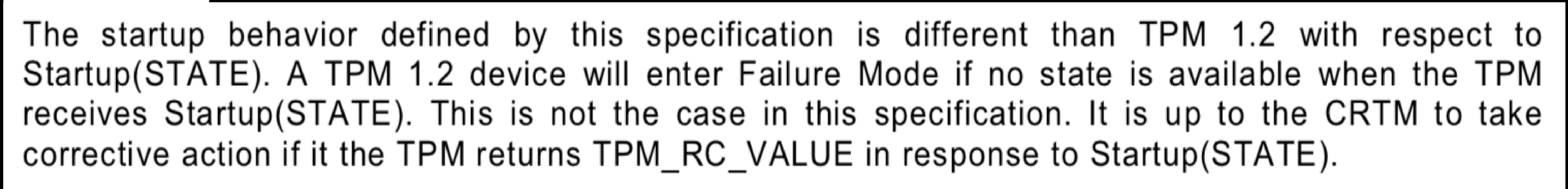
What is the “corrective action”?



If the TPM receives Startup(STATE) that was not preceded by Shutdown(STATE), then there is no state to restore and the TPM will return TPM_RC_VALUE. The CRTM is expected to take corrective action to prevent malicious software from manipulating the PCR values such that they would misrepresent the state of the platform. The CRTM would abort the Startup(State) and restart with Startup(CLEAR).

This means “reset the TPM”

TPM 1.2



The startup behavior defined by this specification is different than TPM 1.2 with respect to Startup(STATE). A TPM 1.2 device will enter Failure Mode if no state is available when the TPM receives Startup(STATE). This is not the case in this specification. It is up to the CRTM to take corrective action if it the TPM returns TPM_RC_VALUE in response to Startup(STATE).

<Trusted Platform Module Library Part1: Architecture Specification>

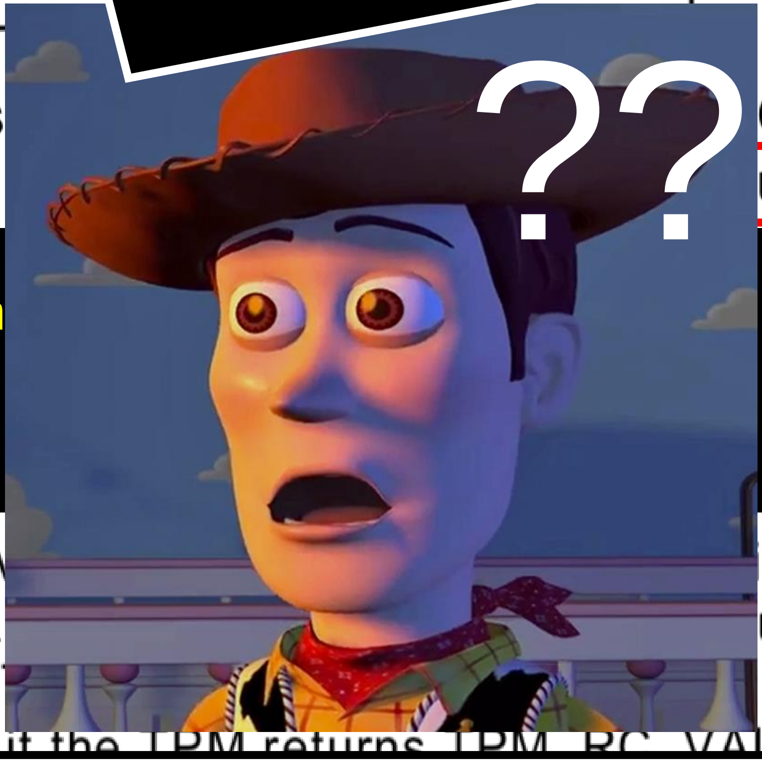
I have no idea about "corrective action"

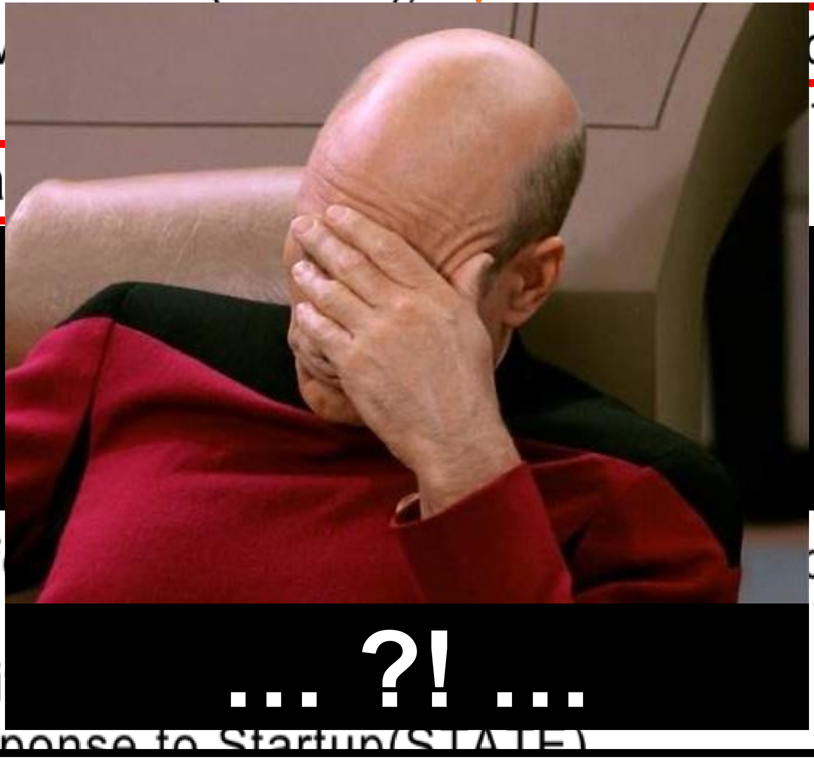
I should do nothing!

TPM 2.0

If the TPM … is no state
to restore and the T… The CRTM… on to
prevent malicious s… CR values … t the
state of the platform … up(State) a…

This m…





TPM 1.2

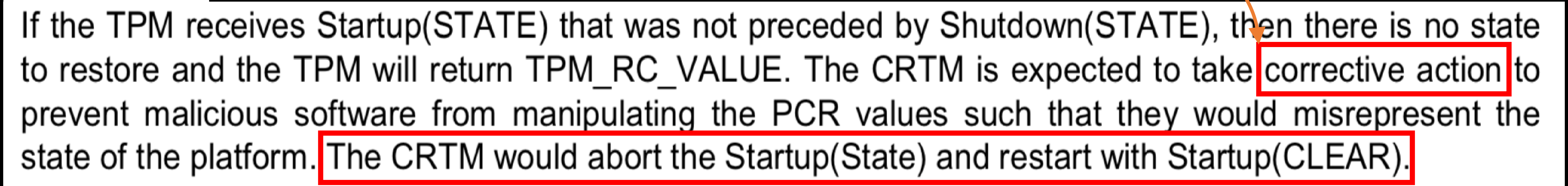
The startup behav… on is diff… ct to
Startup(STATE). A… ure Mode … TPM
receives Startup(S… this speci… take
corrective action if it the TPM returns TPM_RC_VALUE in response to Startup(STATE).

intel DELL hp Lenovo ASUS GIGABYTE™

"Grey Area" Vulnerability (2) (CVE-2018-6622)

TPM 2.0

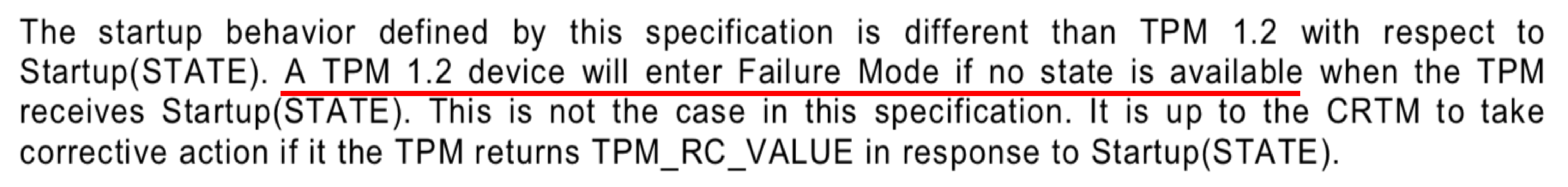
What is the "corrective action"?



If the TPM receives Startup(STATE) that was not preceded by Shutdown(STATE), then there is no state to restore and the TPM will return TPM_RC_VALUE. The CRTM is expected to take corrective action to prevent malicious software from manipulating the PCR values such that they would misrepresent the state of the platform. The CRTM would abort the Startup(State) and restart with Startup(CLEAR).

This means "reset the TPM"

TPM 1.2



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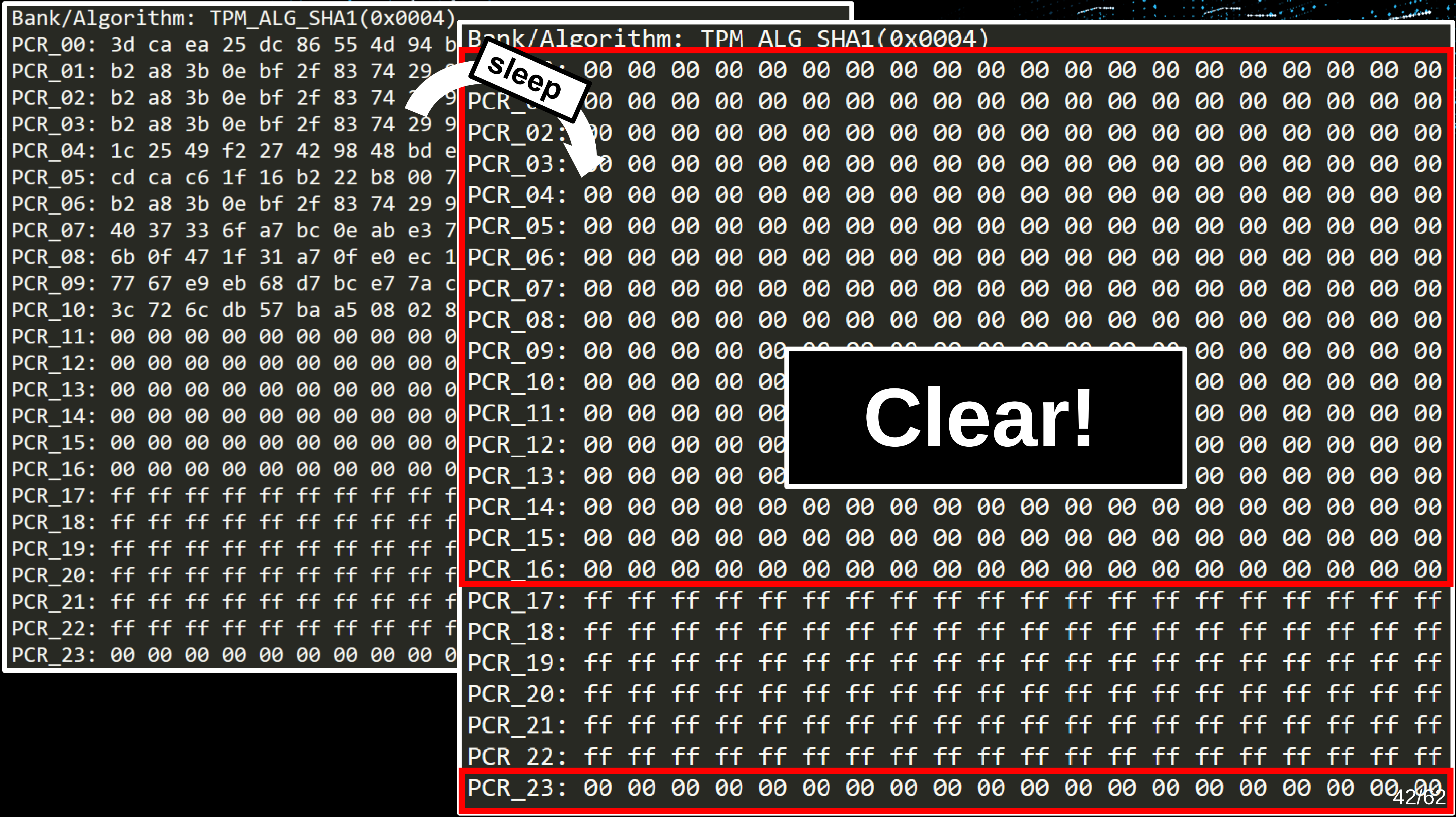
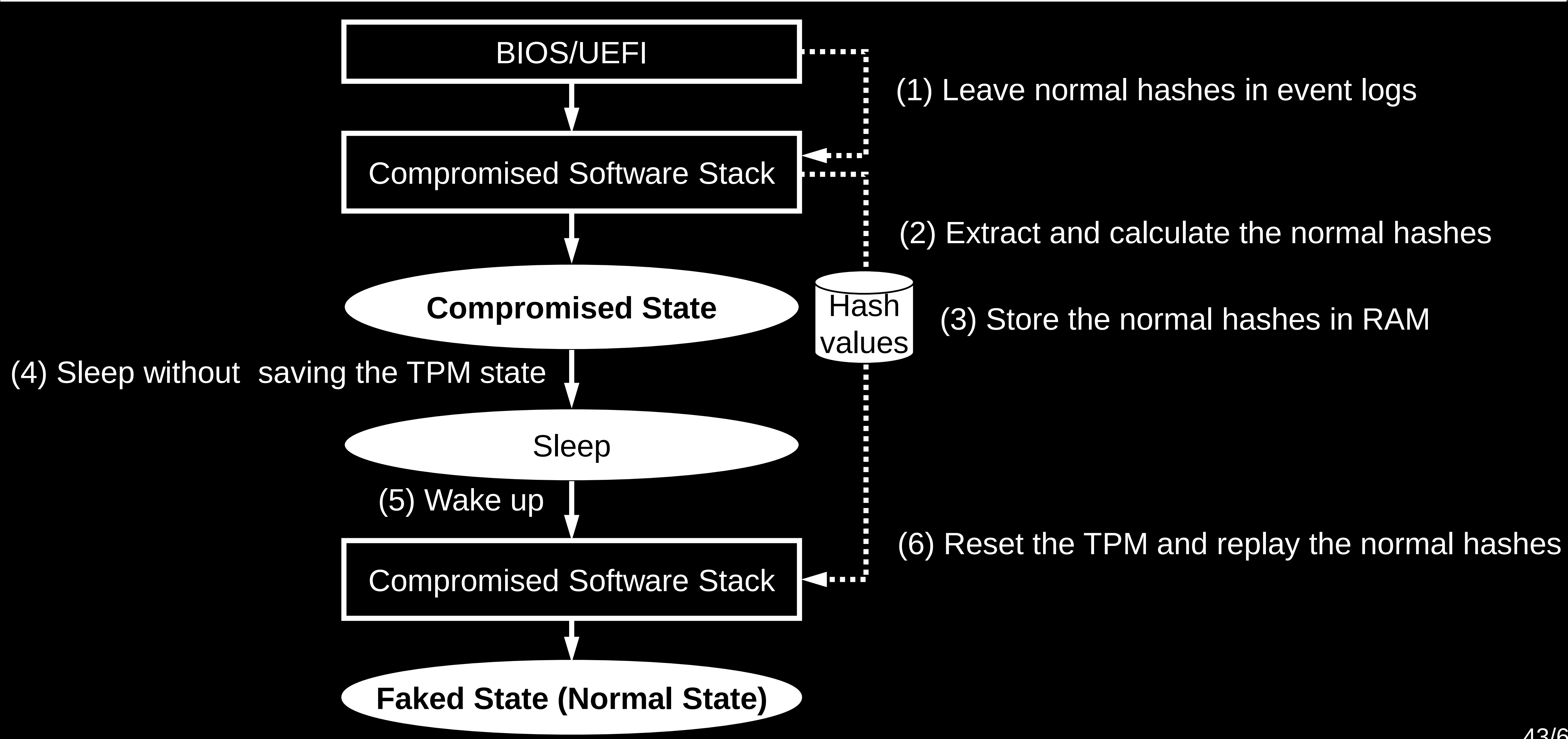
<Trusted Platform Module Library Part1: Architecture Specification>



```
Bank/Algorithm: TPM_ALG_SHA1(0x0004)
PCR_00: 3d ca ea 25 dc 86 55 4d 94 b
PCR_01: b2 a8 3b 0e bf 2f 83 74 29
PCR_02: b2 a8 3b 0e bf 2f 83 74   9
PCR_03: b2 a8 3b 0e bf 2f 83 74 29 9
PCR_04: 1c 25 49 f2 27 42 98 48 bd e
PCR_05: cd ca c6 1f 16 b2 22 b8 00 7
PCR_06: b2 a8 3b 0e bf 2f 83 74 29 9
PCR_07: 40 37 33 6f a7 bc 0e ab e3 7
PCR_08: 6b 0f 47 1f 31 a7 0f e0 ec 1
PCR_09: 77 67 e9 eb 68 d7 bc e7 7a c
PCR_10: 3c 72 6c db 57 ba a5 08 02 8
PCR_11: 00 00 00 00 00 00 00 00 00 0
PCR_12: 00 00 00 00 00 00 00 00 00 0
PCR_13: 00 00 00 00 00 00 00 00 00 0
PCR_14: 00 00 00 00 00 00 00 00 00 0
PCR_15: 00 00 00 00 00 00 00 00 00 0
PCR_16: 00 00 00 00 00 00 00 00 00 0
PCR_17: ff ff ff ff ff ff ff ff ff f
PCR_18: ff ff ff ff ff ff ff ff ff f
PCR_19: ff ff ff ff ff ff ff ff ff f
PCR_20: ff ff ff ff ff ff ff ff ff f
PCR_21: ff ff ff ff ff ff ff ff ff f
PCR_22: ff ff ff ff ff ff ff ff ff f
PCR_23: 00 00 00 00 00 00 00 00 00 0
```

```
Bank/Algorithm: TPM_ALG_SHA1(0x0004)
PCR_00: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_01: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_02: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_03: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_04: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_05: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_06: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_07: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_08: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_09: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_10: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_11: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_12: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_13: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_14: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_15: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_16: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR_17: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_18: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_19: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_20: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_21: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_22: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
PCR_23: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

Exploit Scenario of the CVE-2018-6622


BIOS/UEFI
Compromised Software Stack
Compromised State
Sleep
Compromised Software Stack
Faked State (Normal State)
Hash values

(1) Leave normal hashes in event logs

(2) Extract and calculate the normal hashes

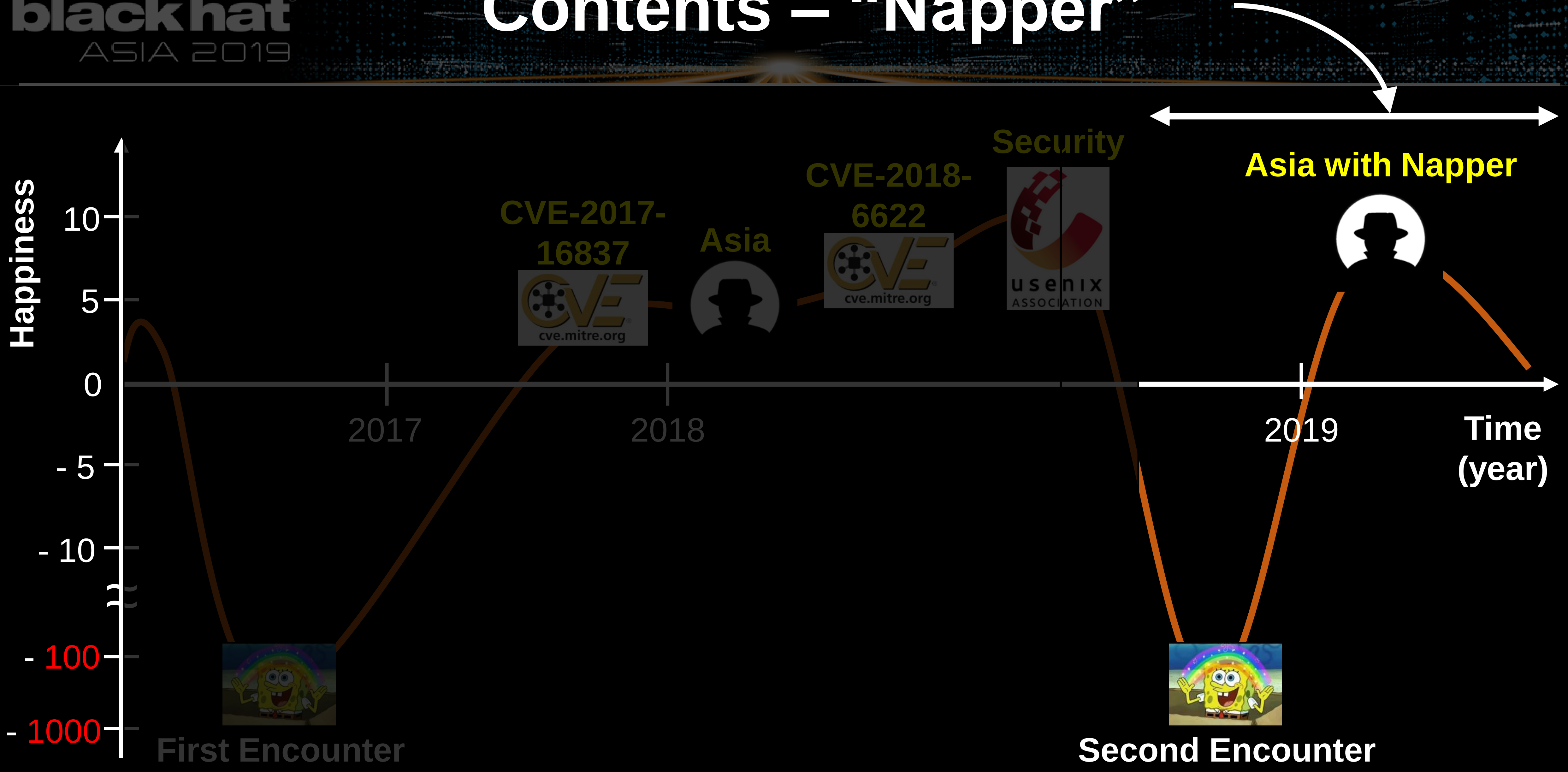
(3) Store the normal hashes in RAM

(4) Sleep without saving the TPM state

(5) Wake up

(6) Reset the TPM and replay the normal hashes

Contents – “Napper”



Every researcher has ONLY ONE work item, until they encounter their manager.

- Unknown

“Napper”?

- **Is a tool that can check the ACPI S3 sleep mode vulnerability in the TPM**
  - It is a bootable USB device based-on Ubuntu 18.04
  - It has a **kernel module** and **user-level applications**
- **Makes the system take a nap and checks the vulnerability**
  - The kernel module exploits the grey area vulnerability (CVE-2018-6622) while sleeping by patching kernel code
  - The user-level applications check the TPM status and show a report

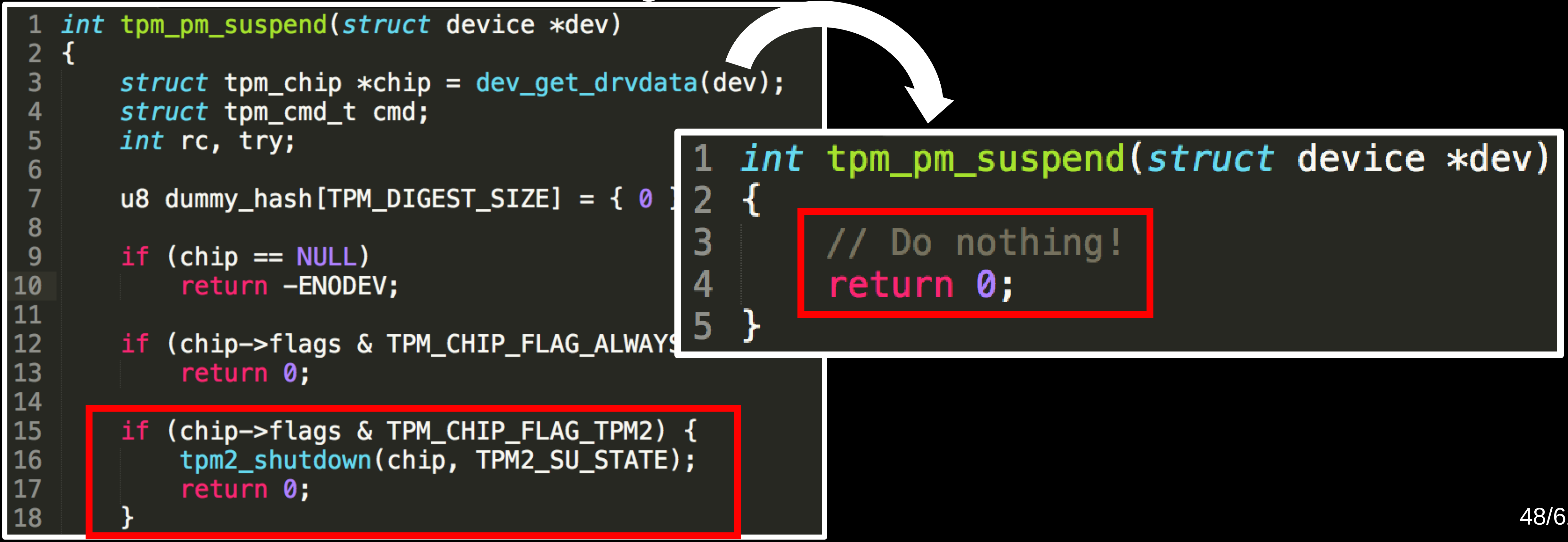
“Napper”?

- **Is a tool that can check the ACPI S3 sleep mode vulnerability in the TPM**
  - It is a bootable USB device based-on Ubuntu 18.04
  - It has a **kernel module** and **user-level applications**
- **Makes the system take a nap and checks the vulnerability**

CVE-2017-16837 is a software vulnerability!
Upgrade tboot if the version is lower than v1.9.7

Napper's Kernel Module (1)

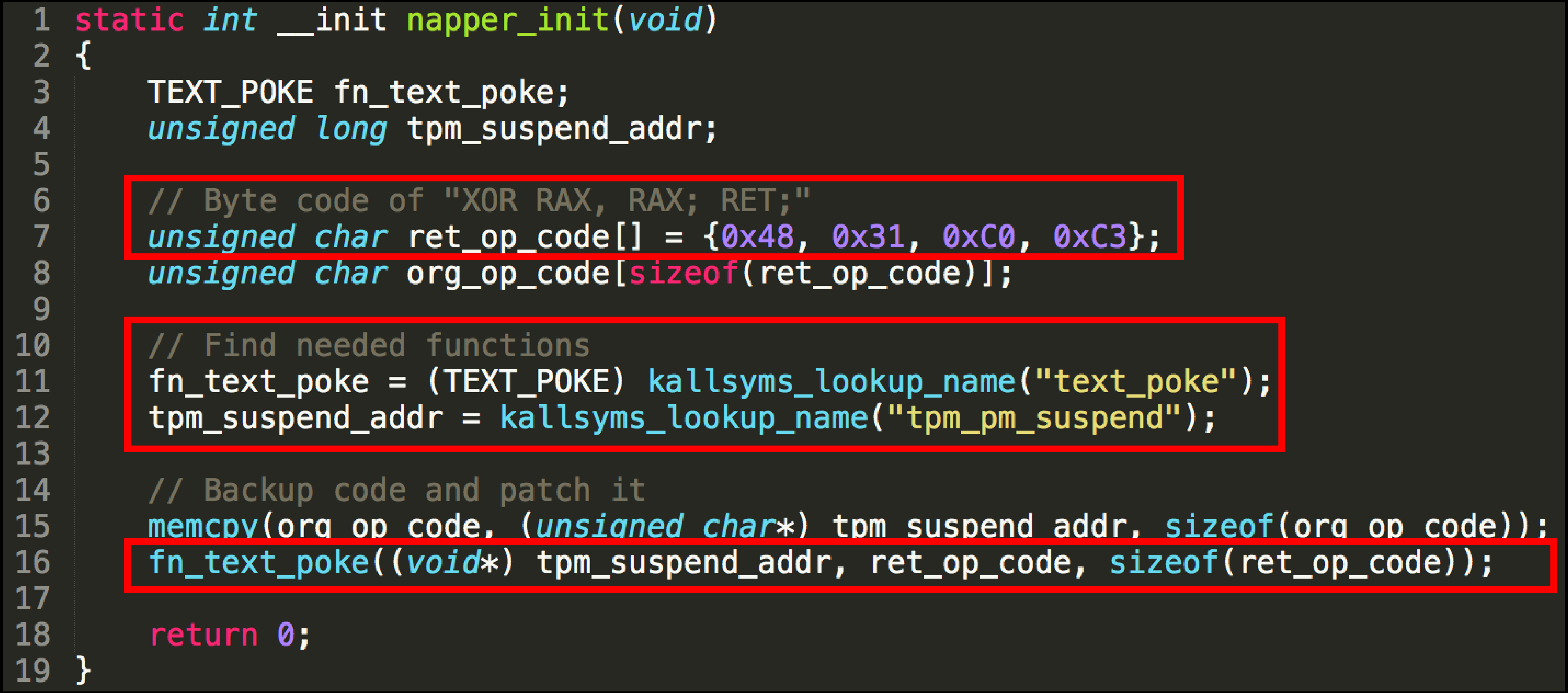
- Patches the **tpm_pm_suspend()** function in TPM driver
  - The function is invoked by kernel while S3 sleep sequence
  - The kernel module changes the function to "**return 0;**"



```c
int tpm_pm_suspend(struct device *dev)
{
	struct tpm_chip *chip = dev_get_drvdata(dev);
	struct tpm_cmd_t cmd;
	int rc, try;

	u8 dummy_hash[TPM_DIGEST_SIZE] = { 0 

	if (chip == NULL)
		return -ENODEV;

	if (chip->flags & TPM_CHIP_FLAG_ALWAYS
		return 0;

	if (chip->flags & TPM_CHIP_FLAG_TPM2) {
		tpm2_shutdown(chip, TPM2_SU_STATE);
		return 0;
	}
```

```c
int tpm_pm_suspend(struct device *dev)
{
	// Do nothing!
	return 0;
}
```

Napper’s Kernel Module (2)



```
static int __init napper_init(void)
{
    TEXT_POKE fn_text_poke;
    unsigned long tpm_suspend_addr;

    // Byte code of "XOR RAX, RAX; RET;"
    unsigned char ret_op_code[] = {0x48, 0x31, 0xC0, 0xC3};
    unsigned char org_op_code[sizeof(ret_op_code)];

    // Find needed functions
    fn_text_poke = (TEXT_POKE) kallsyms_lookup_name("text_poke");
    tpm_suspend_addr = kallsyms_lookup_name("tpm_pm_suspend");

    // Backup code and patch it
    memcpy(org_op_code, (unsigned char*) tpm_suspend_addr, sizeof(org_op_code));
    fn_text_poke((void*) tpm_suspend_addr, ret_op_code, sizeof(ret_op_code));

    return 0;
}
```

Napper's User-Level Applications

- **Consist of TPM-related software and launcher software**
  - We added a command-line tool, "tpm2_extendpcrs", to tpm2_tools
  - We also made a launcher software for easy-of-use
- **Load the kernel module and check the TPM vulnerability**
  - The launcher loads napper's kernel module and takes a nap
  - It checks if **PCRs of the TPM are all ZEROS** and extends PCRs
  - It gathers and reports the TPM and system information with tpm2_getinfo, dmidecode, and journalctl tools

Napper Live-CD and USB Bootable Device

Ubuntu 18.04

+ Kernel 4.18.0-15

+ TPM-related software

+ User-level Applications

+ Pinguybuilder_5.1-7

Napper Live-CD.iso

Napper Live-CD and USB Bootable Device

Ubuntu 18.04

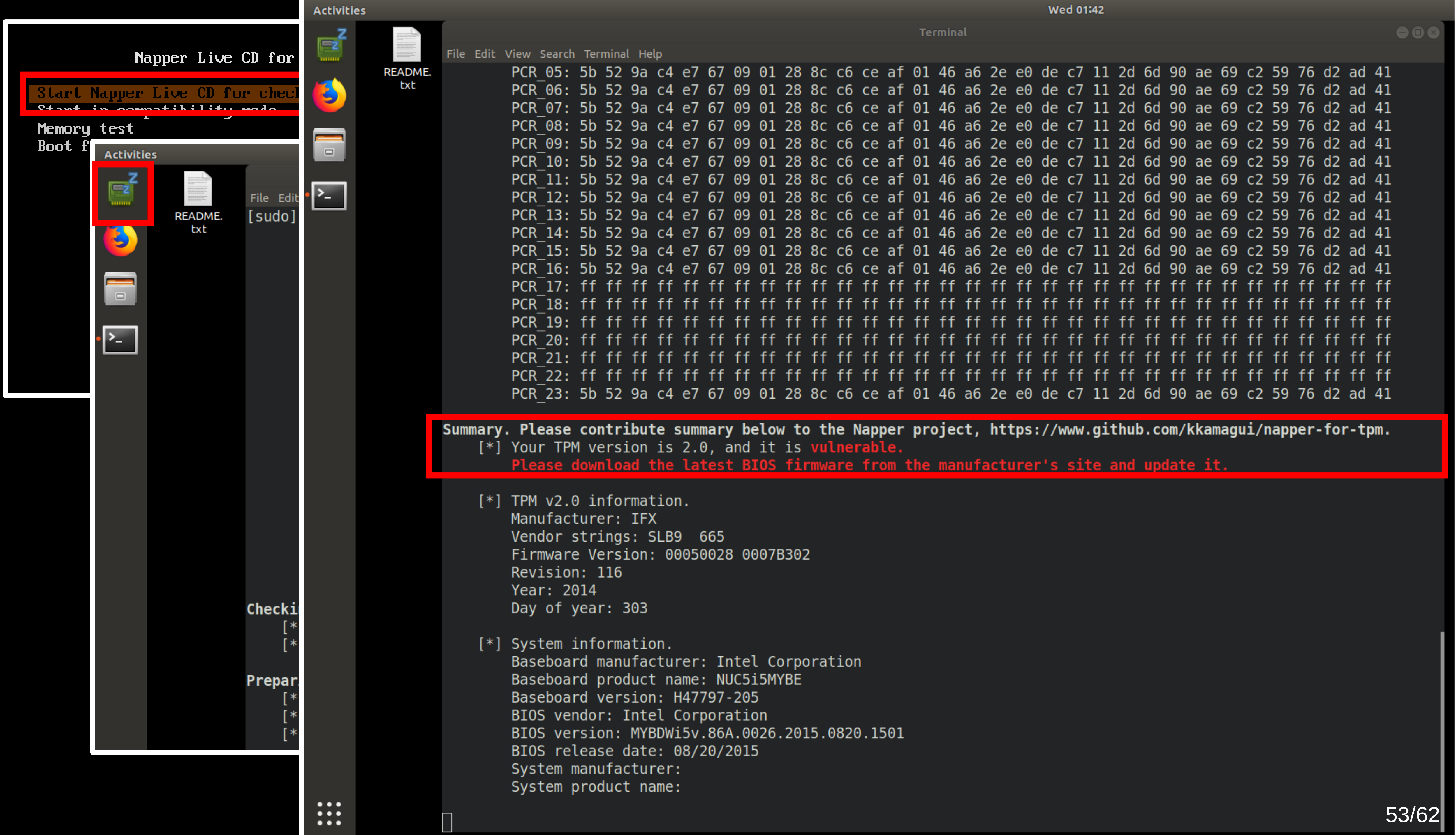
+ Kernel 4.18.0-15

Project page:

https://github.com/kkamagui/napper-for-tpm

+ Pinguybuilder_5.1-7

Napper Live-CD.iso



```
[sudo]

Checki
  [*
  [*

Prepar
  [*
  [*
  [*
```

```
        PCR_05: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_06: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_07: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_08: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_09: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_10: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_11: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_12: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_13: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_14: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_15: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_16: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41
        PCR_17: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
        PCR_18: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
        PCR_19: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
        PCR_20: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
        PCR_21: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
        PCR_22: ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
        PCR_23: 5b 52 9a c4 e7 67 09 01 28 8c c6 ce af 01 46 a6 2e e0 de c7 11 2d 6d 90 ae 69 c2 59 76 d2 ad 41

Summary. Please contribute summary below to the Napper project, https://www.github.com/kkamagui/napper-for-tpm.
    [*] Your TPM version is 2.0, and it is vulnerable.
        Please download the latest BIOS firmware from the manufacturer's site and update it.

    [*] TPM v2.0 information.
        Manufacturer: IFX
        Vendor strings: SLB9  665
        Firmware Version: 00050028 0007B302
        Revision: 116
        Year: 2014
        Day of year: 303

    [*] System information.
        Baseboard manufacturer: Intel Corporation
        Baseboard product name: NUC5i5MYBE
        Baseboard version: H47797-205
        BIOS vendor: Intel Corporation
        BIOS version: MYBDWi5v.86A.0026.2015.0820.1501
        BIOS release date: 08/20/2015
        System manufacturer:
        System product name:
```

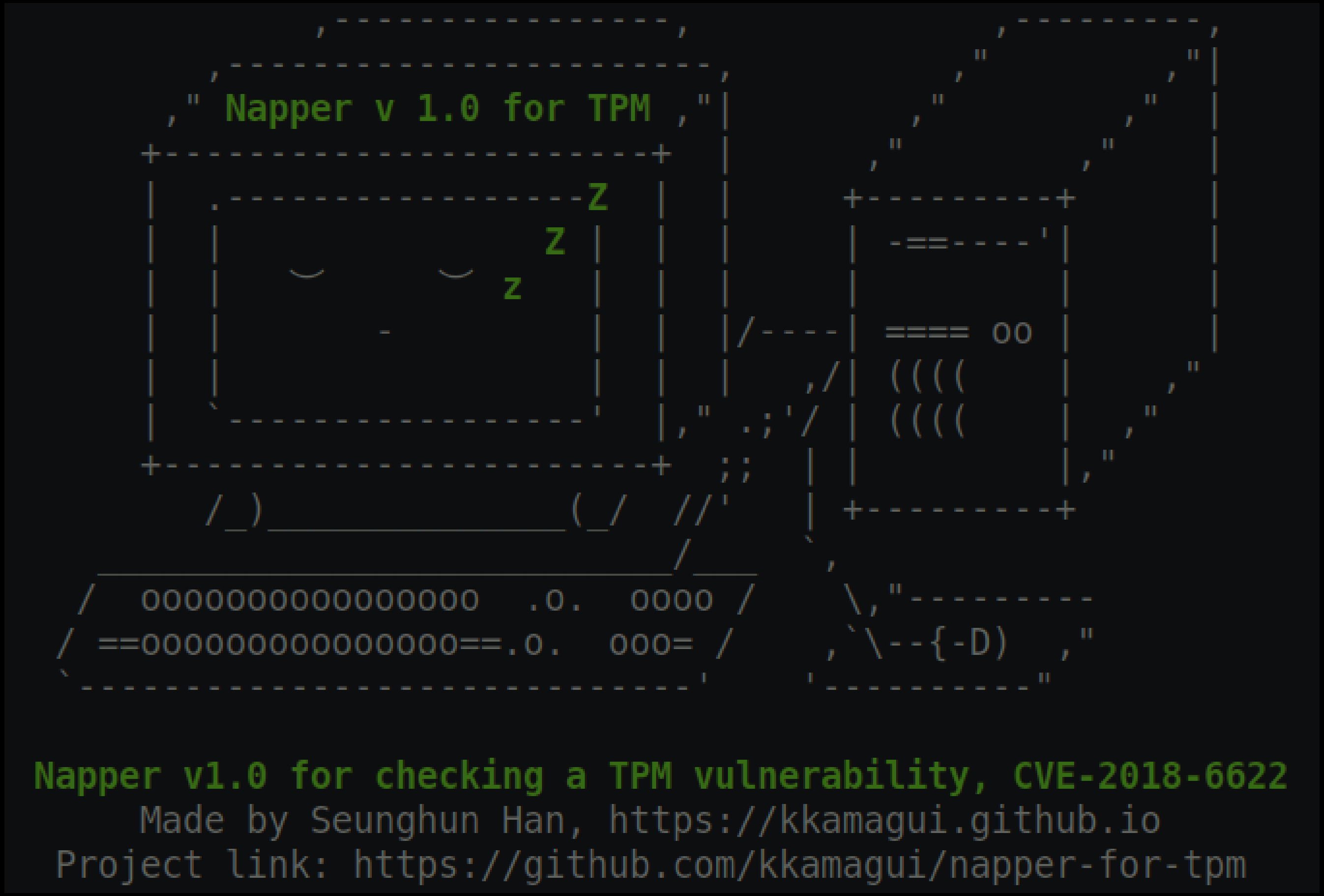
Model	Status	BIOS			TPM	
		Vendor	Version	Release Date	Manufacturer	Vendor String
ASUS Q170M-C	**Vulnerable**	American Megatrends Inc.	4001	11/09/2018	Infineon (IFX)	SLB9665
Dell Optiplex 7040	**Vulnerable**	Dell	1.11.1	10/10/2018	NTC	rls NPCT
Dell Optiplex 7050	**Vulnerable**	Dell	1.11.0	11/01/2018	NTC	rls NPCT
GIGABYTE H170-D3HP	**Vulnerable**	American Megatrends Inc.	F20g	03/09/2018	Infineon (IFX)	SLB9665
GIGABYTE Q170M-MK	**Vulnerable**	American Megatrends Inc.	F23	04/12/2018	Infineon (IFX)	SLB9665
HP Spectre x360	**Vulnerable**	American Megatrends Inc.	F.24	01/07/2019	Infineon (IFX)	SLB9665
Intel NUC5i5MYHE	**Vulnerable**	Intel	MYBDWi5v.86A.0049.2018.1107.1046	11/07/2018	Infineon (IFX)	SLB9665
Lenovo T480 (20L5A00TKR)	**Safe**	Lenovo	N24ET44W (1.19)	11/07/2018	Infineon (IFX)	SLB9670
Lenovo T580	**Safe**	Lenovo	N27ET20W (1.06)	01/22/2018	ST-Microelectronics	
Microsoft Surface Pro 4	**Safe**	Microsoft Corporation	108.2439.769	12/07/2018	Infineon (IFX)	SLB9665

Model	Status	BIOS			TPM	
		Vendor	Version	Release Date	Manufacturer	Vendor String
ASUS Q170M-C	**Vulnerable**	American Megatrends Inc.	4001	11/09/2018	Infineon (IFX)	SLB9665
Dell Optiplex 7040	**Vulnerable**	Dell	1.11.1	10/10/2018	NTC	rls NPCT
Dell Optiplex 7050	**Vulnerable**	Dell	1.11.0	11/01/2018	NTC	rls NPCT
GIGABYTE		American				
Spectre x360		Megatrends Inc.				
Intel NUC5i5MYHE	**Vulnerable**	Intel	MYBDWi5v.86A. 0049.2018. 1107.1046	11/07/2018	Infineon (IFX)	SLB9665
Lenovo T480 (20L5A00TKR)	**Safe**	Lenovo	N24ET44W (1.19)	11/07/2018	Infineon (IFX)	SLB9670
Lenovo T580	**Safe**	Lenovo	N27ET20W (1.06)	01/22/2018	ST-Microelectronics	
Microsoft Surface Pro 4	**Safe**	Microsoft Corporation	108.2439.769	12/07/2018	Infineon (IFX)	SLB9665

The latest result:

https://github.com/kkamagui/napper-for-tpm/#6-test-results

DEMO



```
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 `-----------------------------'    '----------"

Napper v1.0 for checking a TPM vulnerability, CVE-2018-6622
     Made by Seunghun Han, https://kkamagui.github.io
 Project link: https://github.com/kkamagui/napper-for-tpm
```

Countermeasures – CVE-2018-6622 (The Grey Area Vulnerability)

1) **Disable the ACPI S3 sleep feature in BIOS menu**
   - Brutal, but simple and effective

2) **Revise TPM 2.0 specification to define “corrective action” in detail and patch BIOS/UEFI firmware**
   - A long time to revise and apply to the TPM or BIOS/UEFI firmware
   - But, fundamental solutions!

Countermeasures – CVE-2017-16837
(The Lost Pointer Vulnerability)

1) **Apply our patch to tboot**

   - https://sourceforge.net/p/tboot/code/ci/521c58e51eb5be105a29983742850e72c44ed80e/

2) **Update tboot to the latest version**

Conclusion and Black Hat Sound Bytes

- **Two vulnerabilities that can subvert the TPM with the ACPI S3 sleeping state were found**
  - CVE-2017-16837 and CVE-2018-6622
- **Napper is a bootable USB device and can check the TPM vulnerability easily**
  - Check your system with Napper or visit the project site for the results
- **Update your BIOS/UEFI firmware with latest version**
  - If there is no patched firmware yet, disable the ACPI S3 sleep feature in BIOS menu right now!

Acknowledgements

Gwan-gyeong Mun

Researcher at Intel

Junyoung Jung

at Mobile & Embedded System Lab. of Kyung Hee University

Juneseok Byun

at Lab, the 2nd brain & the 3rd eye of Hongik University

JaeRyoung Oh

CEO of Blackfort Security, Inc.

Matt Oh

Security researcher

Seong Bin Park

Anti-cheat engine developer and malware researcher at wellbia.com

Sung Ki Park

Microsoft MVP in Windows and device for IT

Yonghwan Roh

CEO of Somma, Inc.

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Questions ?

CONTRIBUTION!

Project : https://github.com/kkamagui/napper-for-tpm

Contact: hanseunghun@nsr.re.kr, @kkamagui1
parkparkqw@nsr.re.kr, @DavePark312

Reference

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