Using the TPM NVRAM to Protect Secure Boot Keys in OpenPOWER

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Outline

- **Introduction**
  OpenPOWER Secure Boot Overview
- **Problem Statement**
- **Protecting Secure Boot Keys in OpenPOWER**
  Data stored in the TPM NV
  Authorization for the TPM NV data
- **Final Considerations**

OpenPOWER Secure Boot Team

IBM Linux Technology Center

IBM POWER Firmware

IBM LTC Security

IBM Research

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What is Secure Boot for?

Secure boot aims to prevent untrusted code from loading during the platform boot

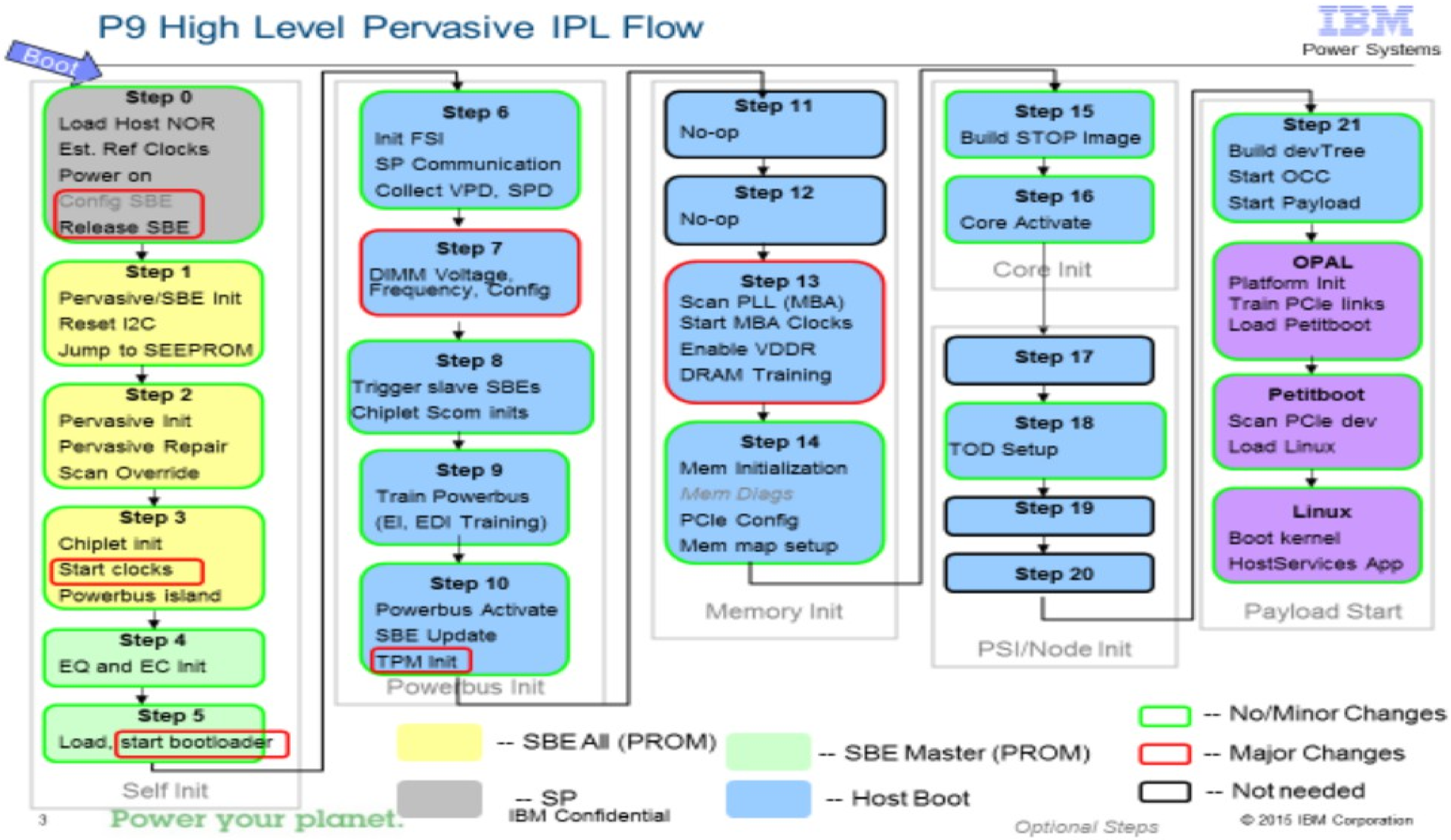
Only code signed with trusted keys are started

OpenPOWER Secure Boot

- The OpenPOWER firmware is open-source
  - https://github.com/open-power/
  - op-build

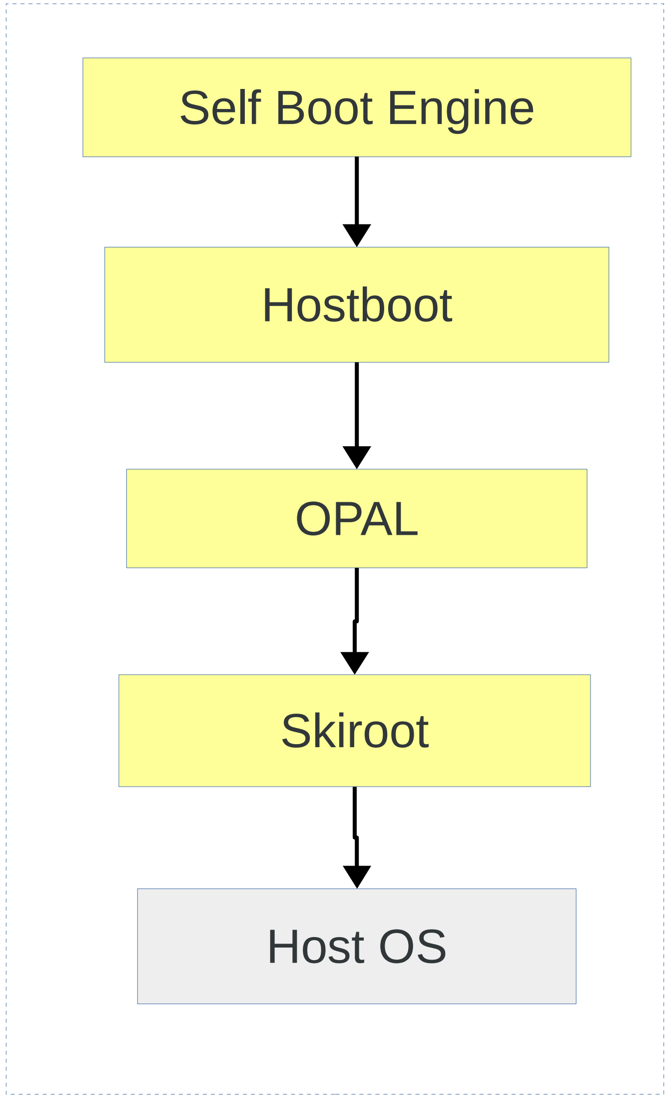
- Domains:
  - Firmware Secure Boot
  - OS Secure Boot

POWER9 Boot Flow



*Source: https://github.com/open-power/docs/blob/master/hostboot/P9_Boot_Flow_OpenPOWER.pdf

Firmware Secure Boot



Very Simplified IPL Flow

- Firmware images are signed following the secure boot container layout (sb-signing-tools)
- Root of trust: hardware keys hash
- Enabled by a hardware setting in the motherboard (platform dependent)

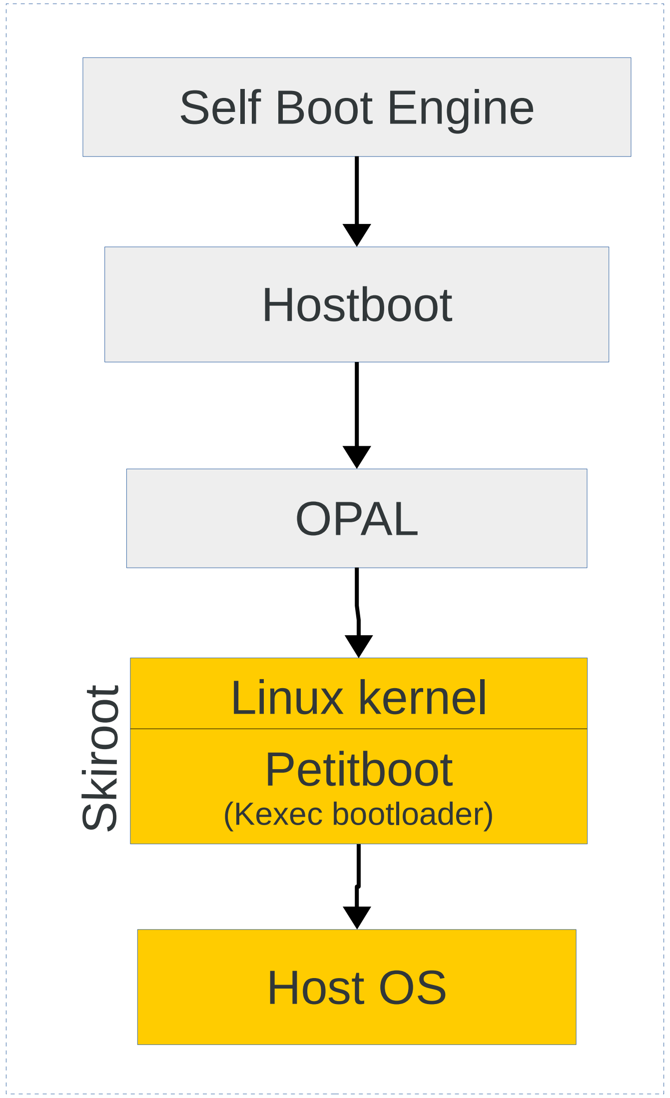
Firmware Secure Boot is Upstream

Secure mode disabled
Secure boot will not be enforced

This is the skiroot

```
[cclaudio@localhost ~]$ grep STB /sys/firmware/opal/msglog
[   69.056932895,3] STB: container NOT VERIFIED, resource_id=4 secureboot not yet initialized
[   69.256328750,5] STB: Found ibm,secureboot-v2
[   69.256387874,5] STB: secure mode off
[   69.256409780,6] STB: Found CVC @ 200ffd1d0000-200ffd1dffff
[   69.256411167,6] STB: Found CVC-sha512 @ 200ffd1d0040, version=1
[   69.256412497,6] STB: Found CVC-verify @ 200ffd1d0050, version=1
[   69.256431826,5] STB: Found tpm0,i2c_tpm_nuvoton evLogLen=2174 evLogSize=65536
[   69.383155960,5] STB: trusted mode on
[   70.511731190,5] STB: IMA_CATALOG verified
[   70.511936383,5] STB: IMA_CATALOG hash calculated
[   71.043208171,5] STB: IMA_CATALOG measured on pcr2 (tpm0, evType 0x5, evLogLen 2257)
[   71.383439064,5] STB: CAPP verified
[   71.383707310,5] STB: CAPP hash calculated
[   71.426871893,5] STB: CAPP measured on pcr2 (tpm0, evType 0x5, evLogLen 2333)
[   79.462183541,5] STB: BOOTKERNEL verified
[   79.492754100,5] STB: BOOTKERNEL hash calculated
[   80.024420917,5] STB: BOOTKERNEL measured on pcr4 (tpm0, evType 0x5, evLogLen 2415)
[   80.453220510,5] STB: EV_SEPARATOR measured on pcr0 (tpm0, evType 0x4, evLogLen 2491)
[   80.497174564,5] STB: EV_SEPARATOR measured on pcr1 (tpm0, evType 0x4, evLogLen 2567)
[   81.028419907,5] STB: EV_SEPARATOR measured on pcr2 (tpm0, evType 0x4, evLogLen 2643)
[   81.071664532,5] STB: EV_SEPARATOR measured on pcr3 (tpm0, evType 0x4, evLogLen 2719)
[   81.114942755,5] STB: EV_SEPARATOR measured on pcr4 (tpm0, evType 0x4, evLogLen 2795)
[   81.158264748,5] STB: EV_SEPARATOR measured on pcr5 (tpm0, evType 0x4, evLogLen 2871)
[   81.201673492,5] STB: EV_SEPARATOR measured on pcr6 (tpm0, evType 0x4, evLogLen 2947)
[   81.244920149,5] STB: EV_SEPARATOR measured on pcr7 (tpm0, evType 0x4, evLogLen 3023)
[cclaudio@localhost ~]$ lsprop /sys/firmware/devicetree/base/ibm,secureboot/
hw-key-hash-size 00000040 (64)
trusted-enabled
compatible       "ibm,secureboot-v2"
phandle          000000b3 (179)
hw-key-hash      40d487ff 7380ed6a d54775d5 795fea0d
                 e2f541fe a9db06b8 466a42a3 20e65f75
                 b4866546 0017d907 515dc2a5 f9fc5095
                 4d6ee0c9 b67d219d fb708535 1d01d6d1
name             "ibm,secureboot"
[cclaudio@localhost ~]$
```

OS Secure Boot



Very Simplified IPL Flow

- The OS Secure Boot work is in progress
- Skiroot is a linux kernel with embedded initramfs that runs Petitboot – a kexec bootloader

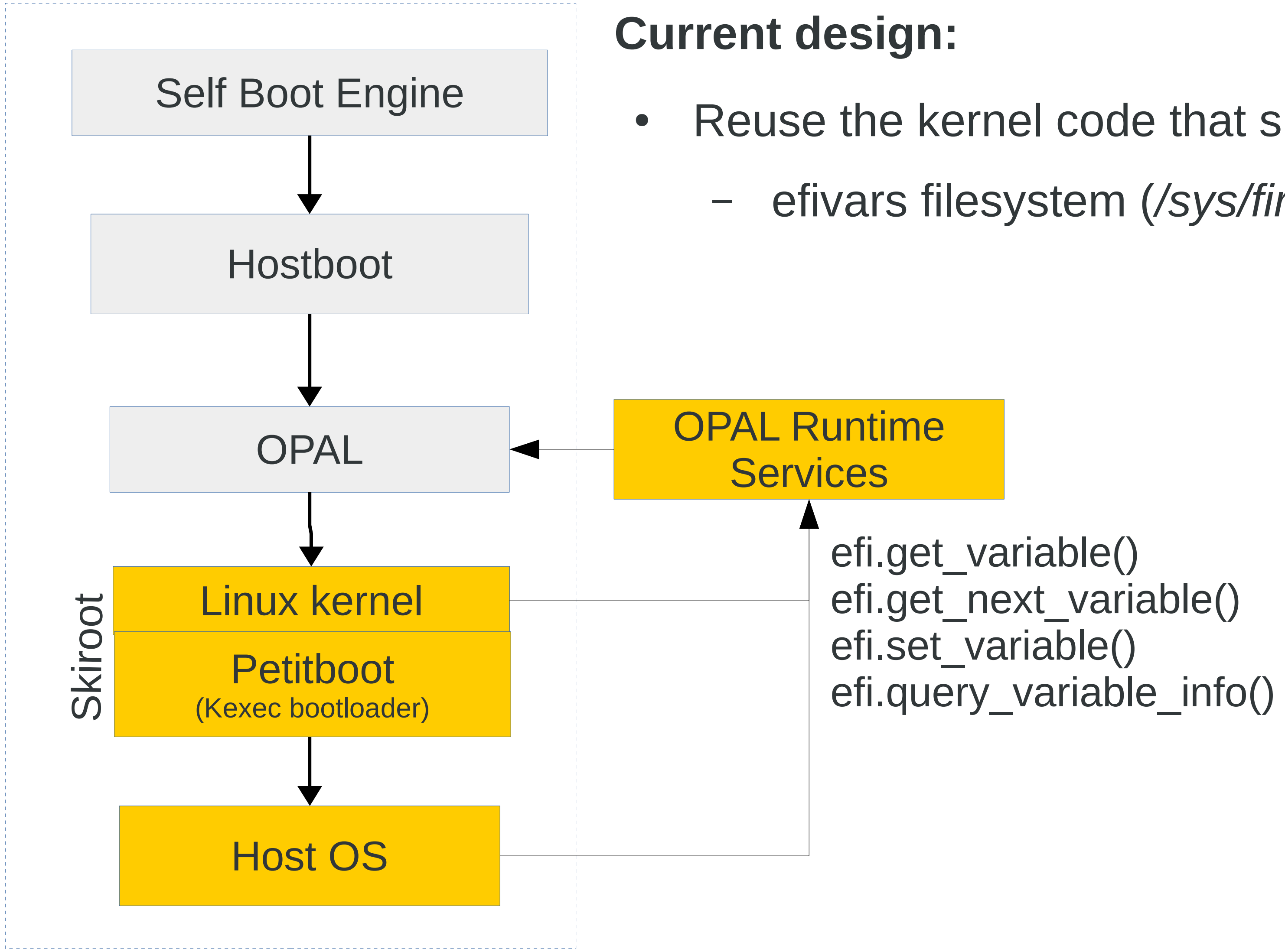
Current design:

- Host OS kernel:
  - It is signed with *sign-file*, the same tool used to sign kernel modules. The signature is appended
  - It is verified by IMA-appraisal

OS Secure Boot (cont'd)

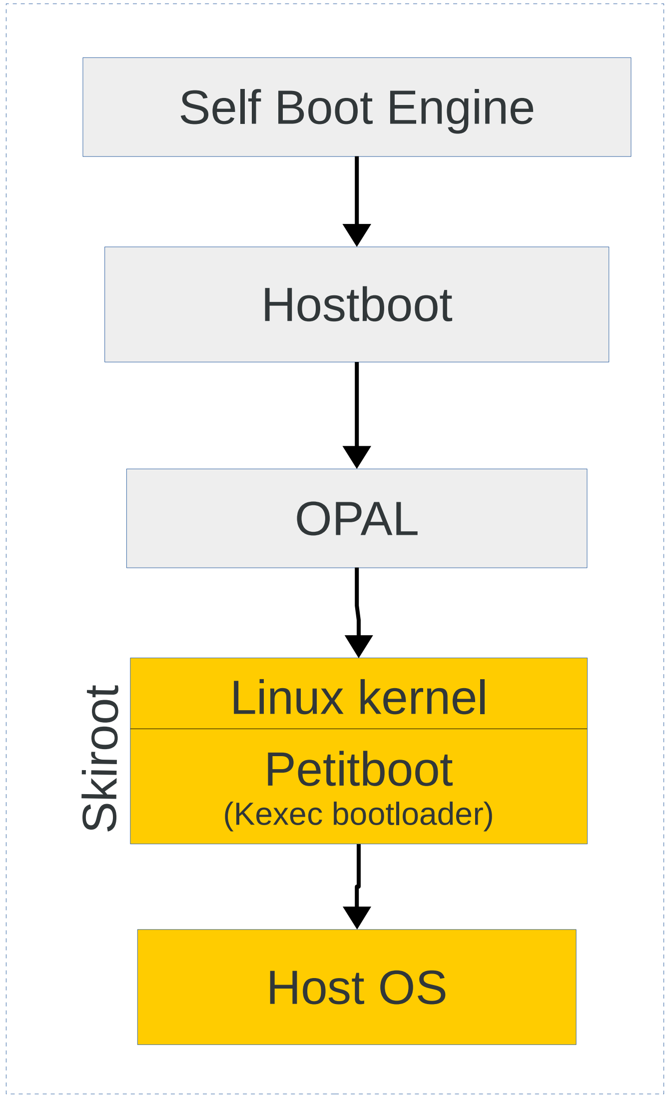
Current design:

- Reuse the kernel code that supports EFI as much as possible:
  - efivars filesystem (*/sys/firmware/efi/efivars/*) Prototyped



Very Simplified IPL Flow

OS Secure Boot (cont'd)

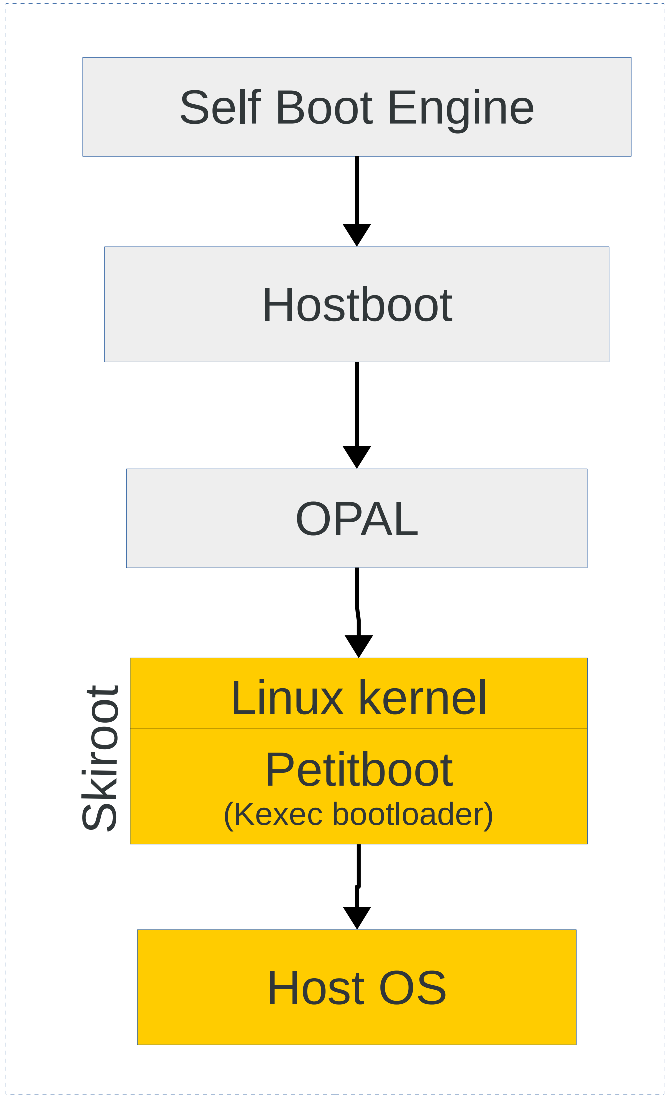


Very Simplified IPL Flow

Current design:

- We are in the process to request distros to build the efivar package on powerpc64le
- Secure boot variables: X.509 certificates
  - Platform Key (PK)
    - Root of trust for the OS Secure Boot
    - When PK is set, OS Secure boot policy is enforced
  - Key Exchange Key (KEK)
  - Authorized Signature Database (db)

Problem Statement



Very Simplified IPL Flow

- Firmware Secure Boot keystore:
  - hw-key-hash → SEEPROM
- OS Secure Boot keystore:
  - PK, KEK and db → PNOR SECBOOT partition (~128KB)
- **PNOR is unprotected by design, attackers could have their malicious code executed, for example.**
- Trusted Platform Module (TPM) 2.0 provides protected non-volatile (NV) memory
- There is no space in the TPM2 NV for all secure boot variables

Protecting the OS Secure Boot Keys

- Integrity
- TPM2 NV authorization
- Where each variable should be stored?
- Atomic variable update

OS Secure Boot Keys: Integrity

- Keys might be modified in the PNOR without notice
- **Detect** keys integrity issues using a SHA512 hash
- Keys are consumed only if valid

- PK
- KEK
- db

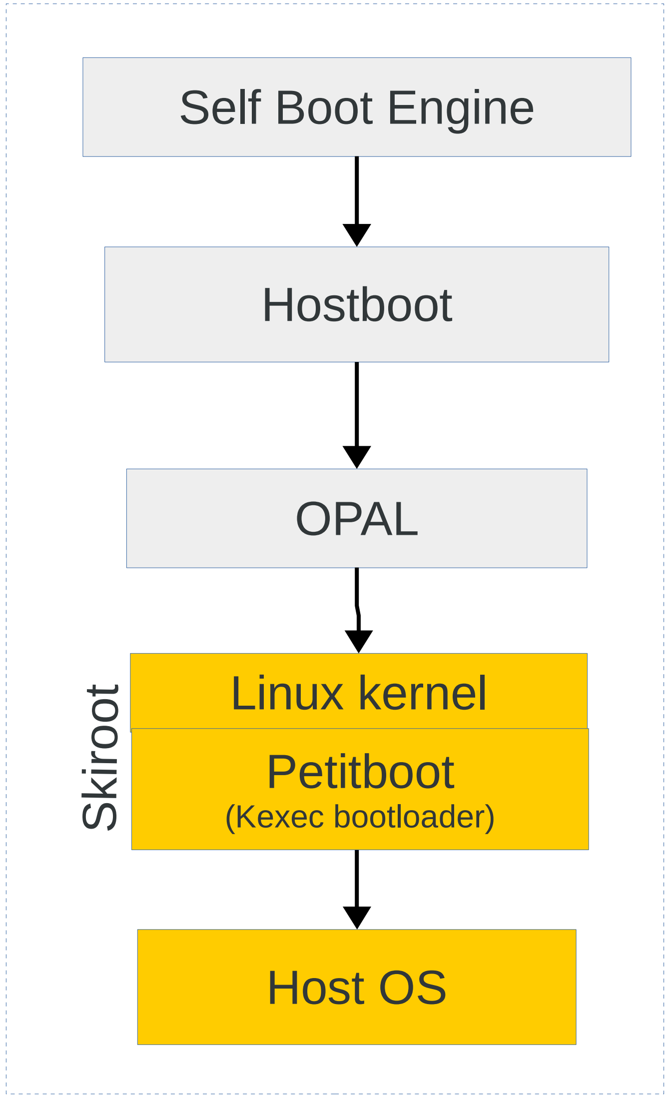
PNOR SECBOOT

- sha2_hash
- sha2_hash_size

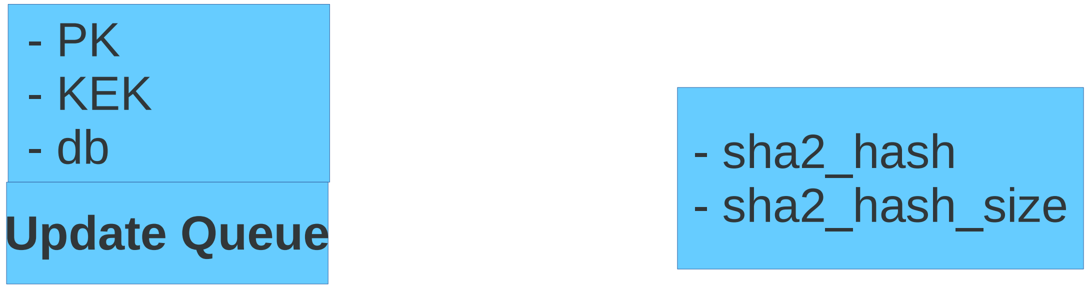
TPM2 NV

TPM2 NV Authorization

- Access control required for the data stored in the TPM2 NV
- NV memory allocated is write locked at boot time until next boot
- Key updates are processed during the skiroot kernel boot



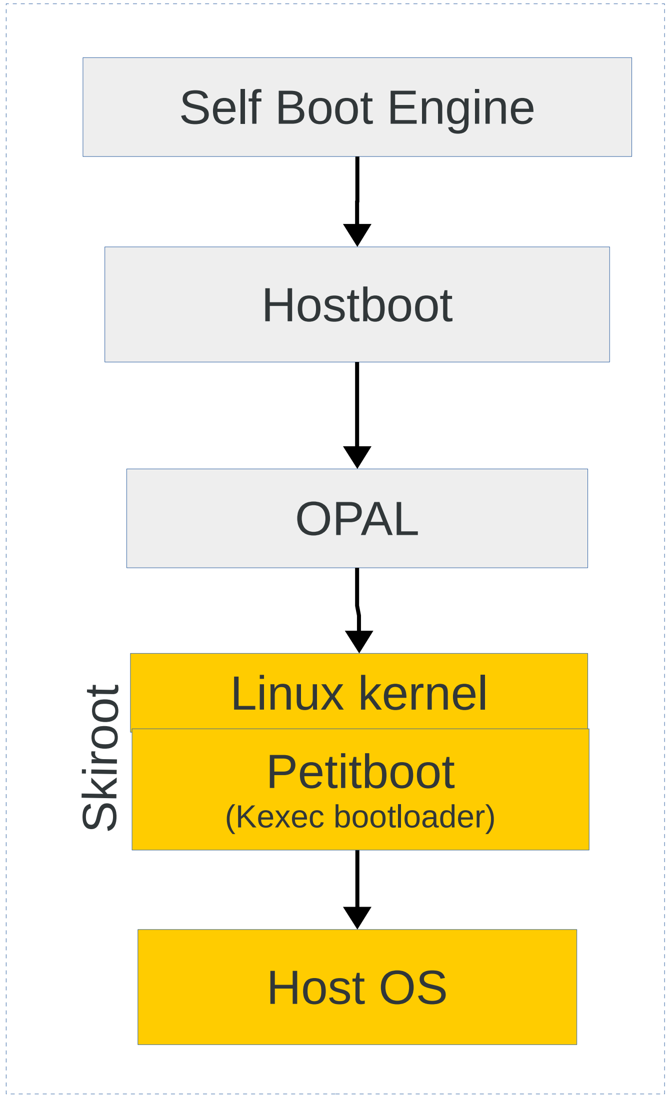
Very Simplified IPL Flow



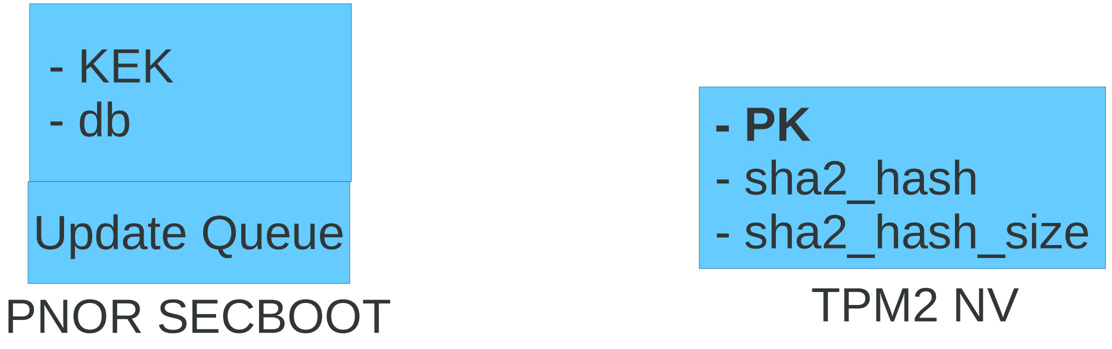
PNOR SECBOOT

TPM2 NV

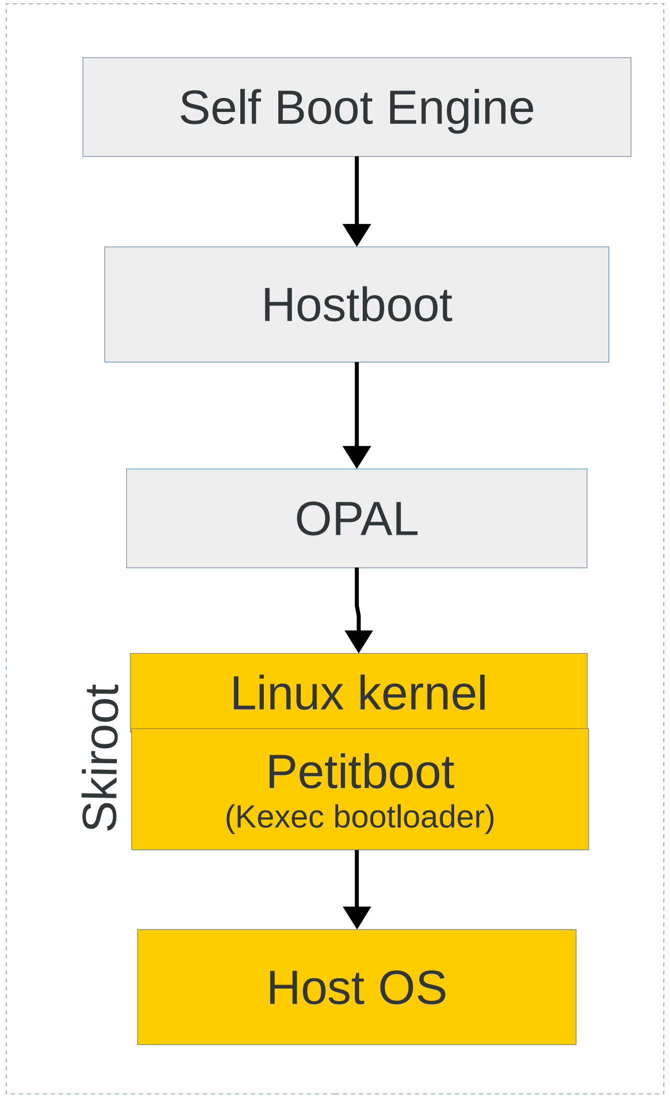
Where Each Variable Should be Stored?



- If PK is lost, the root of trust is lost
- PK is stored in the TPM2 NV
- No special procedure required to recover KEK and db

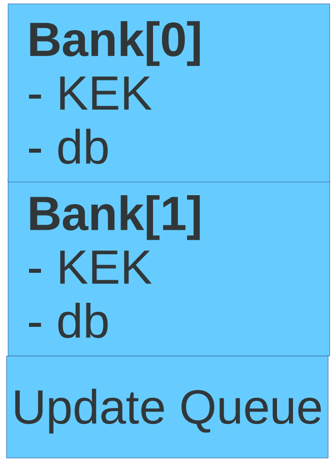


Atomic Secure Boot Variable Update

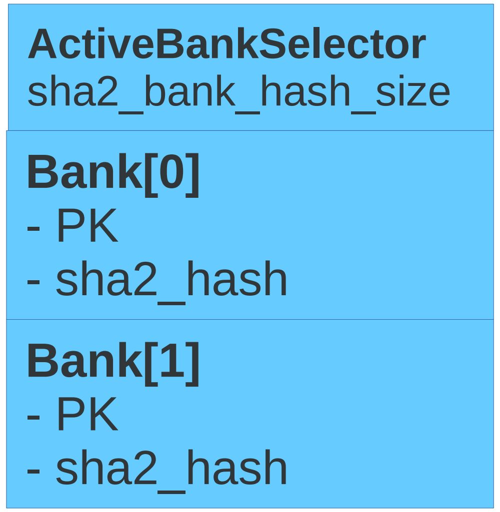


Very Simplified IPL Flow

- Writes to the storage might be interrupted
- ActiveBankSelector bit determines which is the current active bank
- Updates are persisted in the staging bank
- Flip the ActiveBankSelector bit and reboot



PNOR SECBOOT



TPM2 NV

OS Secure Boot NV Indices

Define the OS NV indices

```
[root@localhost utils]$ ./nvdefinespace -ha 01c10191 -hi p -hia p \
> -sz 6    -at ppr +at ar +at wst -pwdn ""
nvdefinespace: success
[root@localhost utils]$ ./nvdefinespace -ha 01c10192 -hi p -hia p \
> -sz 1088 -at ppr +at ar +at wst -pwdn ""
nvdefinespace: success
[root@localhost utils]$ ./nvdefinespace -ha 01c10193 -hi p -hia p \
> -sz 1088 -at ppr +at ar +at wst -pwdn ""
nvdefinespace: success
[root@localhost utils]$
```

os-nv-header

os-nv-bank0

os-nv-bank1

Read the os-nv-header index public info

```
[root@localhost utils]$ ./nvreadpublic -ha 01c10191
nvreadpublic: name algorithm 000b
nvreadpublic: data size 6
nvreadpublic: attributes 42044005
TPMA_NV_PPWRITE
TPMA_NV_AUTHWRITE
TPM_NT_ORDINARY
TPMA_NV_WRITE_STCLEAR
TPMA_NV_AUTHREAD
TPMA_NV_NO_DA
TPMA_NV_PLATFORMCREATE
 nvreadpublic: policy length 0

 nvreadpublic: name length 34
 00 0b 27 35 82 6b 0f 3e f1 de 4c 00 b2 f1 c6 41
 2b 68 95 b4 1a 1c f4 aa f4 7d e9 3c 5c ec 16 f8
 81 67
[root@localhost utils]$
```

- IBM's TPM 2.0 TSS* is open-source
- Max NV Index size = 2048 bytes
- Same attributes, but different sizes
- Write-locked at boot time until next boot

ActiveBankSelector	**(2 bytes)**
sha2_bank_hash_size	(4 bytes)
Bank[0]	
- PK	(1024 bytes)
- sha2_bank_hash	(64 bytes)
Bank[1]	
- PK	(1024 bytes)
- sha2_bank_hash	(64 bytes)

NV data for OS Secure Boot

Total size = ~2182 bytes

* TCG Software Stack (TSS)

Firmware Secure Boot NV Index

Define the Firmware NV index

```
[root@localhost utils]$ ./nvdefinespace -ha 01c10190 -hi p -hia p \
> -sz 64     -at ppr +at ar +at wst -pwdn ""
nvdefinespace: success
[root@localhost utils]$
```

Read the os-nv-header index public info

```
[root@localhost utils]$ ./nvreadpublic -ha 01c10190
nvreadpublic: name algorithm 000b
nvreadpublic: data size 64
nvreadpublic: attributes 42044005
TPMA_NV_PPWRITE
TPMA_NV_AUTHWRITE
TPM_NT_ORDINARY
TPMA_NV_WRITE_STCLEAR
TPMA_NV_AUTHREAD
TPMA_NV_NO_DA
TPMA_NV_PLATFORMCREATE
 nvreadpublic: policy length 0

 nvreadpublic: name length 34
 00 0b 59 bc 8f a6 03 9d c8 66 0a 27 68 90 ab 43
 95 73 5c 29 a7 f3 2d 03 c1 c2 10 17 6c 7e bf 9f
 ee d8
[root@localhost utils]$
```

- Hardware Key Hash* (64 bytes)

NV data for Firmware Secure Boot

Total size = 64 bytes

* The OS platform key is invalidated when the underlying hardware keys change

Other TPM2 NV Commands

Read and write to the NV index

```
[root@localhost utils]$ ./nvwrite -ha 01c10192 -hia p -pwdn "" -ic "LinuxSecuritySummit"
[root@localhost utils]$ ./nvread -ha 01c10192 -pwdn "" -sz 30 -of lss.txt
 nvread: data length 30
 4c 69 6e 75 78 53 65 63 75 72 69 74 79 53 75 6d
 6d 69 74 00 00 00 00 00 00 00 00 00 00 00
[root@localhost utils]$
[root@localhost utils]$ hexdump -C lss.txt
00000000  4c 69 6e 75 78 53 65 63  75 72 69 74 79 53 75 6d  |LinuxSecuritySum|
00000010  6d 69 74 00 00 00 00 00  00 00 00 00 00 00        |mit...........|
0000001e
[root@localhost utils]$
```

Write lock the NV Index until the next TPM Reset or TPM Restart

```
[root@localhost utils]$ ./nvwritelock -ha 01c10192 -hia p -pwdn ""
[root@localhost utils]$ ./nvwrite -ha 01c10192 -hia p -pwdn "" -ic "foobar"
nvwrite: failed, rc 00000148
TPM_RC_NV_LOCKED - NV access locked.
[root@localhost utils]$
```

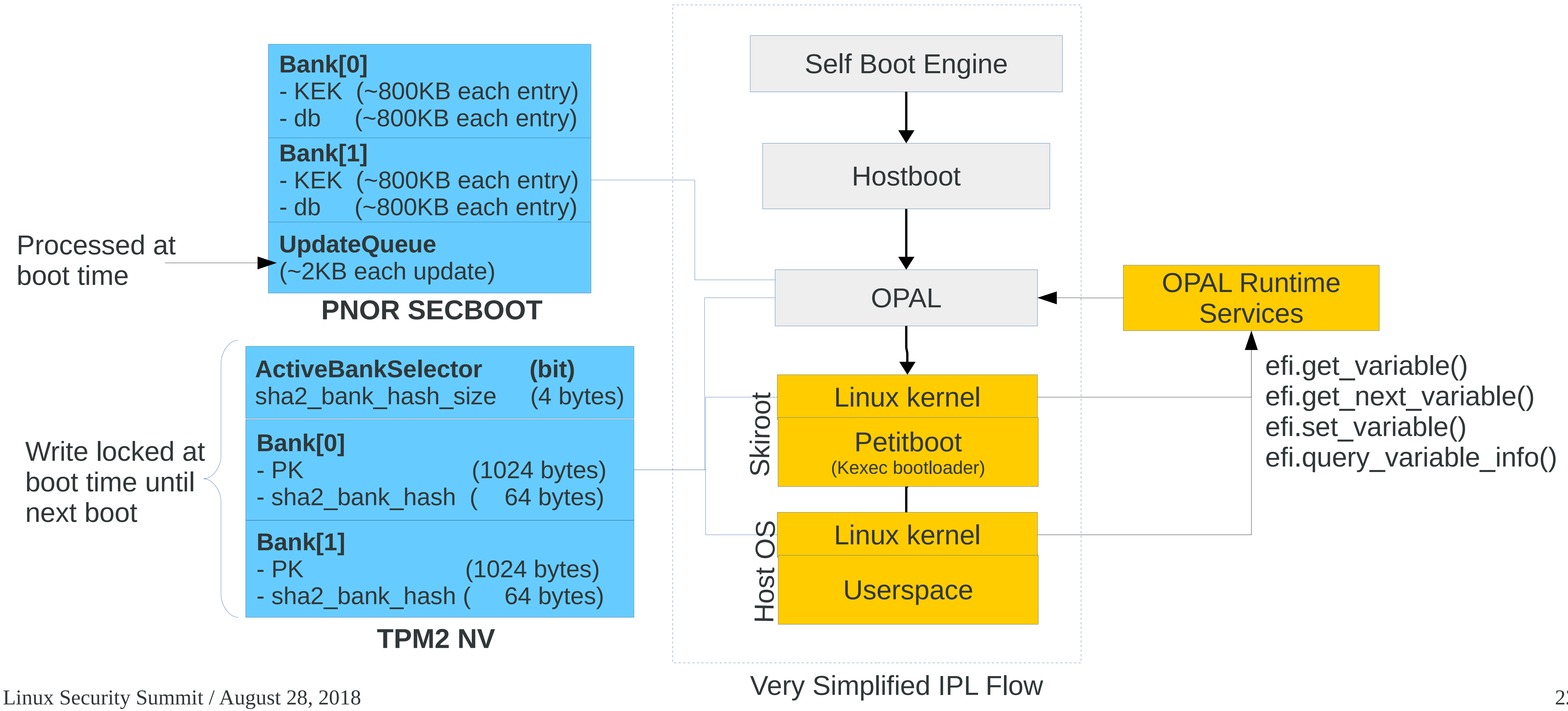
Undefine the NV Index

```
[root@localhost utils]$ ./nvundefinespace -ha 01c10192 -hi p
[root@localhost utils]$ ./nvreadpublic -ha 01c10192
nvreadpublic: failed, rc 0000018b
TPM_RC_HANDLE - the handle is not correct for the use Handle number 1
[root@localhost utils]$
```

Set the platform authorization default password to “pass4lss”

```
[root@localhost utils]$ ./hierarchychangeauth -hi p -pwda "" -pwdn "pass4lss"
[root@localhost utils]$
```

OS Secure Boot Architecture



Final Considerations

- TPM2 NV has shown a secure and valuable storage to protect secure boot variables
- In POWER9, OpenPOWER OS Secure Boot depends on TPM 2.0
- Sharing TSS code throughout the firmware stack is challenging
- Verbose mode in the IBM's TSS

References

OpenPOWER Foundation
https://openpowerfoundation.org

OpenPOWER Firmware
https://github.com/open-power

POWER9 Boot Flow
https://github.com/open-power/docs/blob/master/hostboot/P9_Boot_Flow_OpenPOWER.pdf

Protecting System Firmware with OpenPOWER Secure Boot
https://www.ibm.com/developerworks/library/l-protect-system-firmware-openpower/index.html

Trusted Platform Module TCG Working Group
https://trustedcomputinggroup.org/work-groups/trusted-platform-module/

IBM's TPM 2.0 TSS
https://sourceforge.net/projects/ibmtpm20tss/

Questions?

Thank you! Obrigado!

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Backup Slides

Creating, Using and Installing Your Own Keys

Create at least three sets of certificates: one for PK, one for KEK and one for db

```
$> openssl req -new -x509 -newkey rsa:2048 -subj "/CN=DB/" \
-keyout db.key -out db.crt -days 3650 -nodes -sha256
```

Sign the UEFI images with your db key

```
$> sbsign --key db.key --cert db.crt --output \
HelloWorld-signed.efi HelloWorld.efi
```

Create authorized variable updates. Repeat for KEK and PK

```
$> cert-to-sig-list db.crt db.esl
$> sign-efi-sig-list -k KEK.key -c KEK.crt db db.esl db.auth
```

Update the variables on your platform, remembering to do PK last.

```
$> sudo efivar -n 8be4df61-93ca-11d2-aa0d-00e098032b8c-PK -w -f PK.auth
$> sudo efivar -n 8be4df61-93ca-11d2-aa0d-00e098032b8c-KEK -w -f KEK.auth
$> sudo efivar -n d719b2cb-3d3a-4596-a3bc-dad00e67656f-db -w -f DB.auth
```

OR

```
$> efi-updatevar -f db.auth db
$> efi-updatevar -f KEK.auth KEK
$> efi-updatevar -f PK.auth PK
```

* Source: https://git.kernel.org/pub/scm/linux/kernel/git/jejb/efitools.git/tree/README

Detecting if the NV index wasn't written yet (TPM 2.0)

```
[root@localhost utils]$ ./nvread -ha 01c10190 -pwdn "" -sz 30
nvread: failed, rc 0000014a
TPM_RC_NV_UNINITIALIZED - an NV Index is used before being initialized
[root@localhost utils]$
[root@localhost utils]$ ./nvwrite -ha 01c10190 -hia p -pwdn "pass4lss" -ic "LinuxSecuritySummit"
[root@localhost utils]$
[root@localhost utils]$ ./nvread -ha 01c10190 -pwdn "" -sz 30 -of lss.txt
 nvread: data length 30
 4c 69 6e 75 78 53 65 63 75 72 69 74 79 53 75 6d
 6d 69 74 00 00 00 00 00 00 00 00 00 00 00
[root@localhost utils]$
[root@localhost utils]$ hexdump -C lss.txt
00000000  4c 69 6e 75 78 53 65 63  75 72 69 74 79 53 75 6d  |LinuxSecuritySum|
00000010  6d 69 74 00 00 00 00 00  00 00 00 00 00 00        |mit...........|
0000001e
[root@localhost utils]$
[root@localhost utils]$ ./nvreadpublic -ha 01c10190
nvreadpublic: name algorithm 000b
nvreadpublic: data size 1024
nvreadpublic: attributes 62054001
TPMA_NV_PPWRITE
TPM_NT_ORDINARY
TPMA_NV_WRITE_STCLEAR
TPMA_NV_PPREAD
TPMA_NV_AUTHREAD
TPMA_NV_NO_DA
TPMA_NV_WRITTEN  <-------------------------
TPMA_NV_PLATFORMCREATE
 nvreadpublic: policy length 0

 nvreadpublic: name length 34
 00 0b 38 fa 00 5d e0 7d 8b c3 80 a1 74 9e ae 3f
 4a 50 c0 20 35 61 56 87 24 f9 90 be 80 95 ad fb
 45 87
[root@localhost utils]$
```

Verbose mode (-v) can be used to inspect TSS commands, specially the byte stream sent and received from the TPM2

```
[root@localhost utils]$ ./nvreadpublic -ha 01c10190 -v
TSS_Execute: Command 00000169 marshal
TSS_Execute_valist: Step 1: initialization
TSS_Execute_valist: Step 5: command encrypt
TSS_Sessions_GetDecryptSession: Found 0 decrypt sessions at 0
TSS_Execute_valist: Step 6 calculate HMACs
TSS_Execute_valist: Step 7 set command authorizations
TSS_Execute_valist: Step 8: process the command
TSS_AuthExecute: Executing TPM2_NV_ReadPublic
TSS_Dev_Open: Opening /dev/tpm0
TSS_Dev_SendCommand: TPM2_NV_ReadPublic
 TSS_Dev_SendCommand length 14
 80 01 00 00 00 0e 00 00 01 69 01 c1 01 90
TSS_Dev_ReceiveCommand:
 TSS_Dev_ReceiveCommand length 62
 80 01 00 00 00 3e 00 00 00 00 00 0e 01 c1 01 90
 00 0b 42 05 40 01 00 00 04 00 00 22 00 0b da a5
 cb bb 5c 2b 8c b3 89 c4 28 9f ec 06 d2 57 d1 3f
 4e b4 cc 83 52 3d 77 0b 1c 2f 39 67 30 68
TSS_Dev_ReceiveCommand: rc 00000000
TSS_Execute_valist: Step 9 get response authorizations
TSS_Execute_valist: Step 13: response decryption
TSS_Sessions_GetEncryptSession: Found 0 encrypt sessions at 0
TSS_Execute: Command 00000169 unmarshal
TSS_Execute: Command 00000169 post processor
TSS_PO_NV_ReadPublic
TSS_Name_Store: File ./h01c10190.bin
TSS_Dev_Close: Closing /dev/tpm0
nvreadpublic: name algorithm 000b
nvreadpublic: data size 1024
nvreadpublic: attributes 42054001
TPMA_NV_PPWRITE
TPM_NT_ORDINARY
TPMA_NV_WRITE_STCLEAR
TPMA_NV_PPREAD
TPMA_NV_AUTHREAD
TPMA_NV_NO_DA
TPMA_NV_PLATFORMCREATE
 nvreadpublic: policy length 0

 nvreadpublic: name length 34
 00 0b da a5 cb bb 5c 2b 8c b3 89 c4 28 9f ec 06
 d2 57 d1 3f 4e b4 cc 83 52 3d 77 0b 1c 2f 39 67
 30 68
nvreadpublic: success
[root@localhost utils]$
```

Last Slide