Software Meets Hardware at Semihalf

Improving security of the FreeBSD boot process

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Presentation plan

- Secure Boot 101
- Secure Boot implementation in UEFI
- FreeBSD veriexec and libsecureboot
- TPM overview
- Measured boot
- Strongswan with TPM

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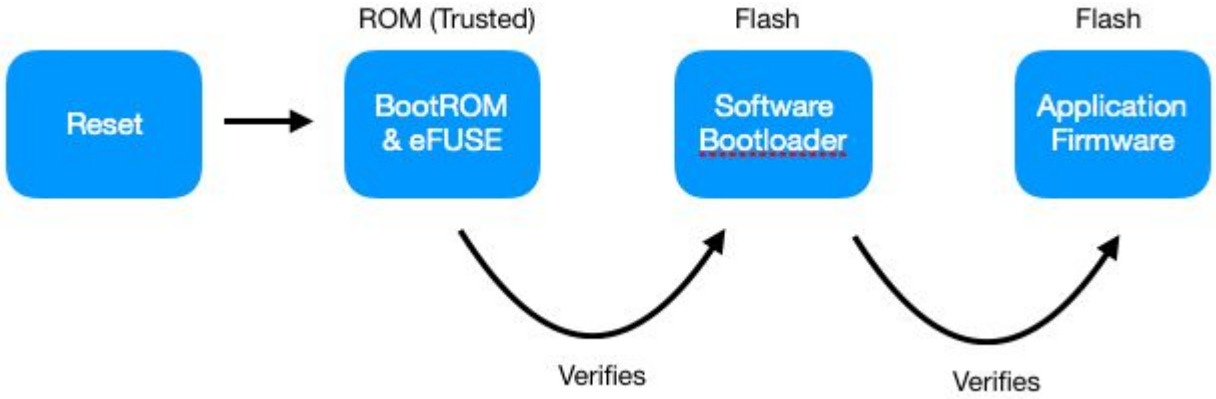
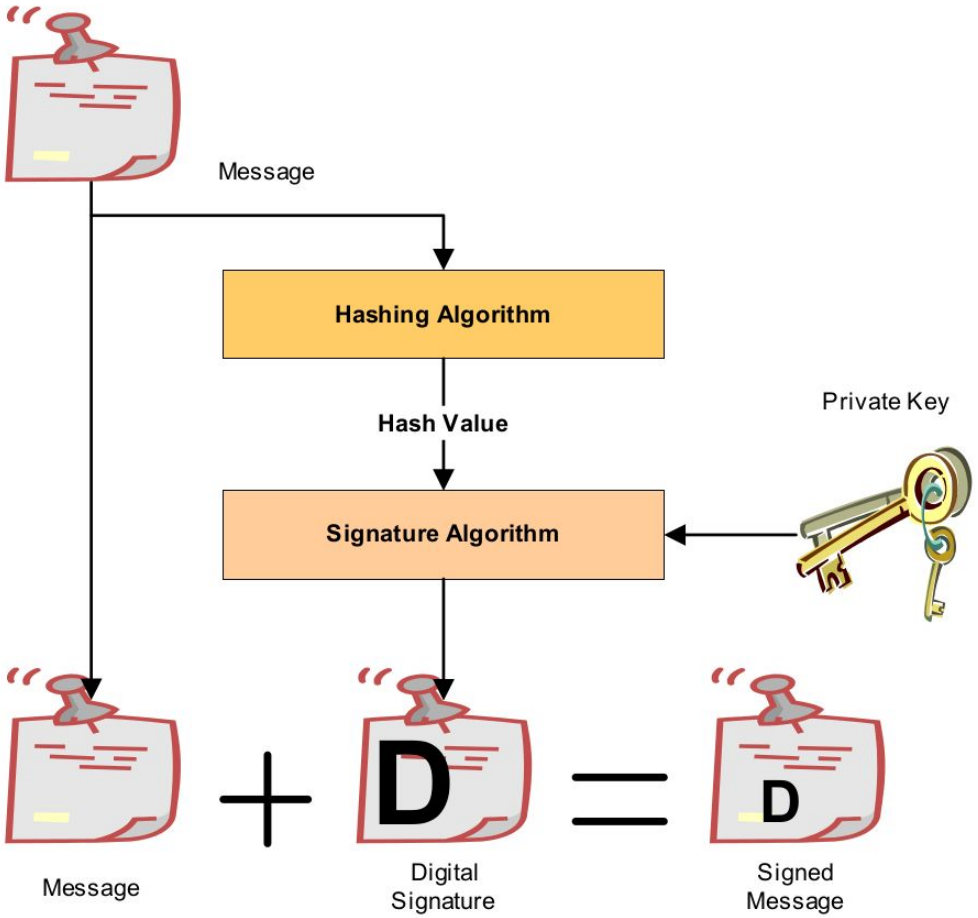
Secure Boot 101

- Purpose - allow only authenticated FW and OS to run
- Defense against rootkits, persistent malware, etc.
- Chain of Trust - each boot image verifies the next, and so on
- Pass execution to next boot image only it verifies OK
- First boot image is immutable (in ROM) - inherently trusted

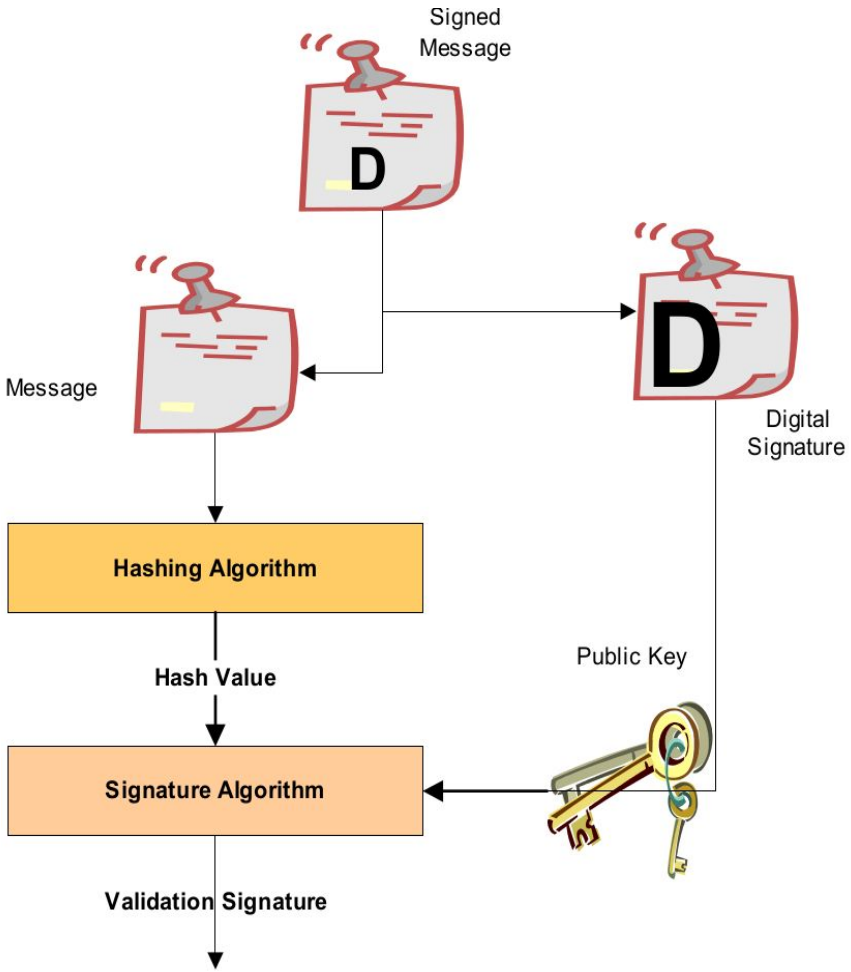
Secure Boot 101

- First image (BootROM) is Root of Trust for the Secure Boot chain
- Root of Trust public key - needs to be protected from modification
- RoT key often burned in fuses, OTP, or ROM (or TPM)





Source: https://uefi.org/sites/default/files/resources/UEFI_Spec_2_7.pdf



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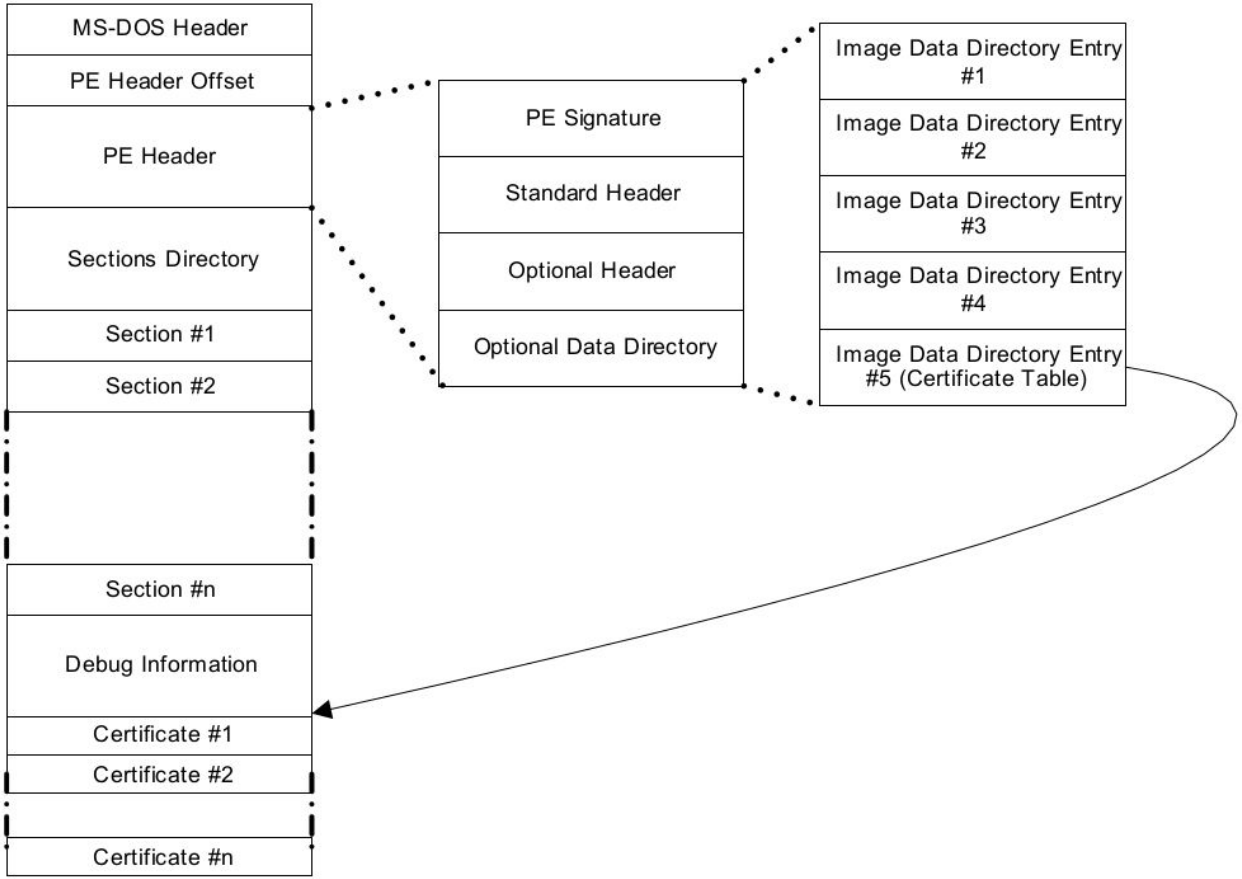
Secure Boot in UEFI

- UEFI uses Microsoft's PE/COFF format for binaries
- PKCS#7 formatted signatures are embedded in the binary
- This format is supported by very few cryptographic libraries.
- The most common open source UEFI implementation - EDK2 is compiled with OpenSSL

Source: https://uefi.org/sites/default/files/resources/UEFI_Spec_2_7.pdf



Source: https://uefi.org/sites/default/files/resources/UEFI_Spec_2_7.pdf

Secure Boot in UEFI

Crucial UEFI variables:

- DB - Database of allowed certificates (for verification)
- DBx - Database of forbidden certificates
- PK - Platform Key, highest at key hierarchy
- KEK - Key Exchange Key, updates to KEK must be signed with PK
- DB/DBx updates must be signed with KEK or PK
- Possibility to whitelist/blacklist specific firmware hashes (no certs)

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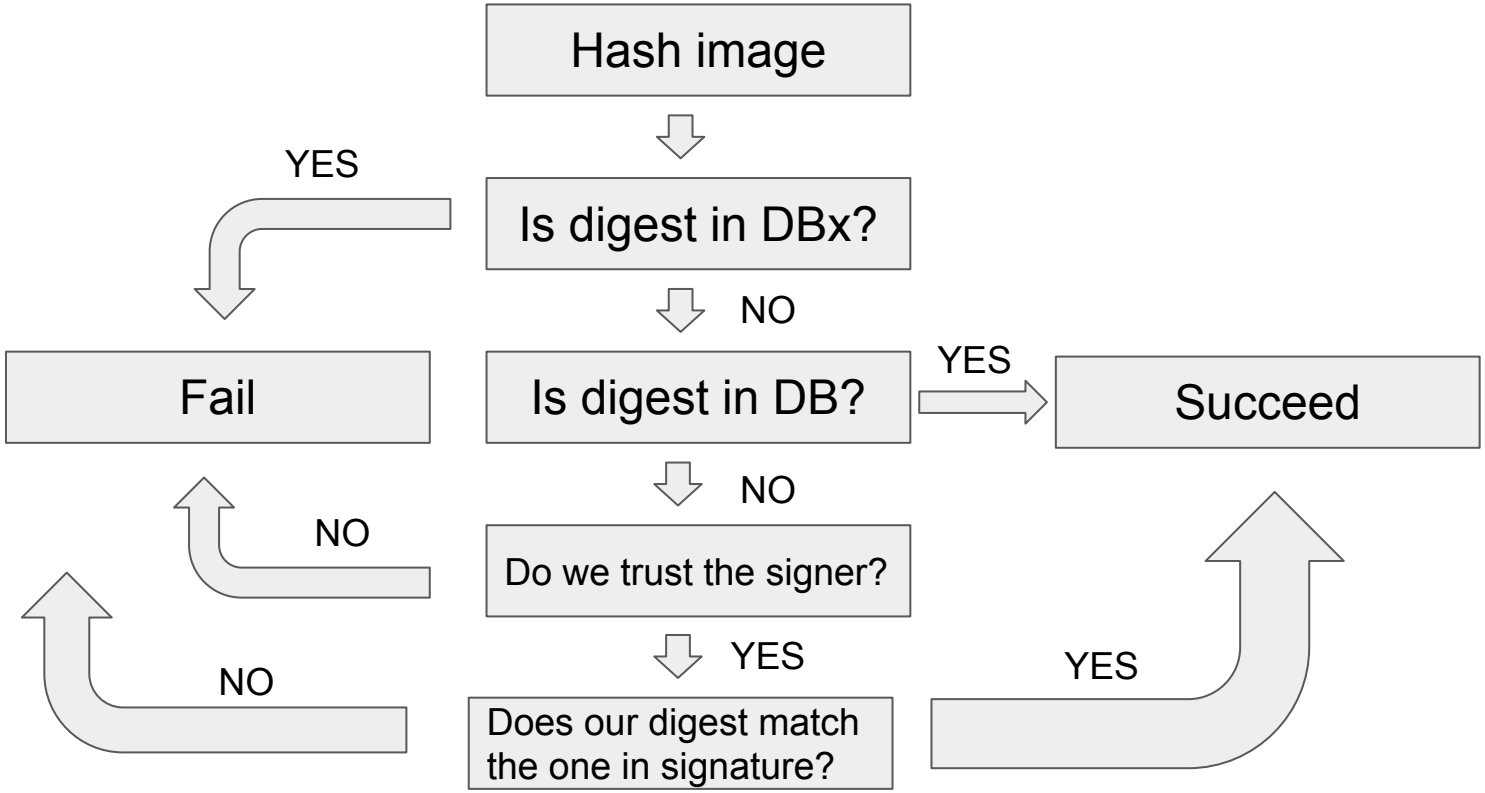

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Veriexec

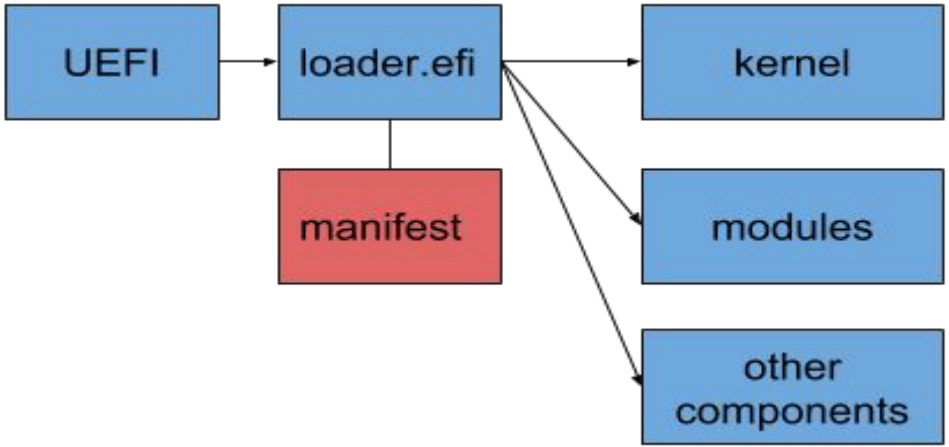
- Juniper created veriexec for Junos OS.
- Available in FreeBSD HEAD since February’19.
- It uses a manifest as a database of trusted components.
- Prevents executing untrusted kernel, binaries, scripts
- Integrity check hooks at execve and other critical points

Veriexec manifest

- Single file composed of entries in path + hash form.
- All of these are loaded into a metadata store, using path as key.
- When a file is loaded, search for its hash in the store.
- If an entry is found and corresponding hash doesn’t match - fail.
- There are different policies for loading kernel
  and other files (eg. config files) when no entry is found.

Verifying the manifest

- Broken chain of trust!
- How to verify the manifest itself?



Verifying the manifest

- Manifest file stored together with its signature
- Trusted public keys may be embedded in the loader
- But we could use UEFI trust anchors for manifest verification
- Loader has access to DB/DBX UEFI variables
- We picked BearSSL - lightweight crypto library to use in the loader
- Library with all the verification API - libsecureboot
- Still, embedded data may be used for systems without UEFI

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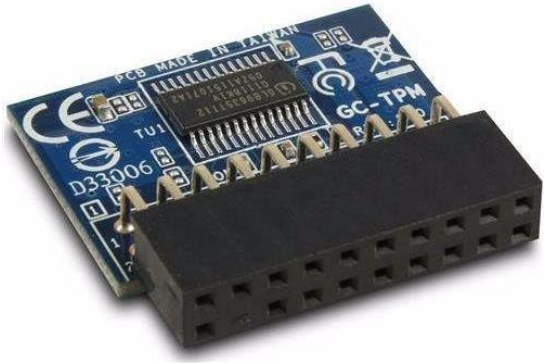
TPM in FreeBSD

- TPM 1.2 driver added in FreeBSD 8.2 (bsssd project)
- TPM 2.0 driver added by Semihalf in Dec 2018
- CRB and FIFO (TIS) modes supported
- LPC bus only (no I2C/SPI support)
- Tested with Infineon SLB9665 TPM

TPM overview

- Trusted Platform Module - a specification by TCG
- Versatile, low-cost HSM device
- Usually a dedicated hardware chip
- Ensures integrity (trustworthiness) of a platform



- Features:
  - - Measured Boot
  - - secure storage (with authorization)
  - - secure key generation
  - - HW RNG
  - - crypto operations (slow!) - RSA, ECC, AES, SHA, HMAC

TPM history

- ~~v1.1 (2003) - now deprecated~~
- v1.2 (2005-2009)
  - - anonymous attestation (DAA)
  - - anti-hammering (prevent dictionary attacks)
  - - limited crypto (SHA-1 only, RSA-2096, no ECC, AES optional)
- v2.0 (2014-2018)
  - - algorithm agility (only max key/hash length defined)
  - - Enhanced Authorization - complex object access rules
  - - not backwards compatible!

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Firmware TPM

- fTPM - TPM implemented in firmware
- Must run in TEE to make sense (ARM TrustZone, SGX)
- Used in millions of mobile devices with TrustZone
- Much faster than discrete TPM - runs on main CPU
- fTPM also in Intel ME, AMD PSP (check your BIOS)

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TPM use cases

- Not just for enterprise!
- Remote attestation - proof of platform/boot integrity
  - (somewhat) proves system is rootkit-free
- 2FA, smart card (GPG) - sign with key embedded in TPM
  - private key never leaves the TPM
- IPSEC VPN hardening - sign IKE payloads with TPM
- MS Bitlocker / LUKS key storage (no GELI support yet..)
  - anti-hammering - TPM locks down on failed attempts
- Securely store root certificates/keys (prevent modification)
- HWRNG entropy for the OS (early boot, embedded systems)

TPM authorization

- Enhanced Authorization in TPM 2.0 allows complex rules
- Each NVRAM object has separate access rules
- Combine multiple rules with AND/OR
- Authorization policies:
  - Password
  - PIN
  - HMAC
  - PCR state (platform/boot integrity)
  - physical presence (press key, assert pin, access BIOS)
  - counters, time limits

TPM caveats

- Anonymity concerns - mostly fixed with TPM 1.2 attestation (DAA)
- DRM concerns - Trusted Computing in general (SGX, Intel ME)
- Discrete TPMs are slow
- Different pinout/pin pitch configurations
- Complex, hard to read spec - 2 versions
- Poor SW support, especially for 2.0
- Hard to use correctly:
  - Bus encryption optional (need PSK)
  - ACPI reset vulnerabilities (PCRs cleared)
  - Need to update TPM FW manually (do it!)

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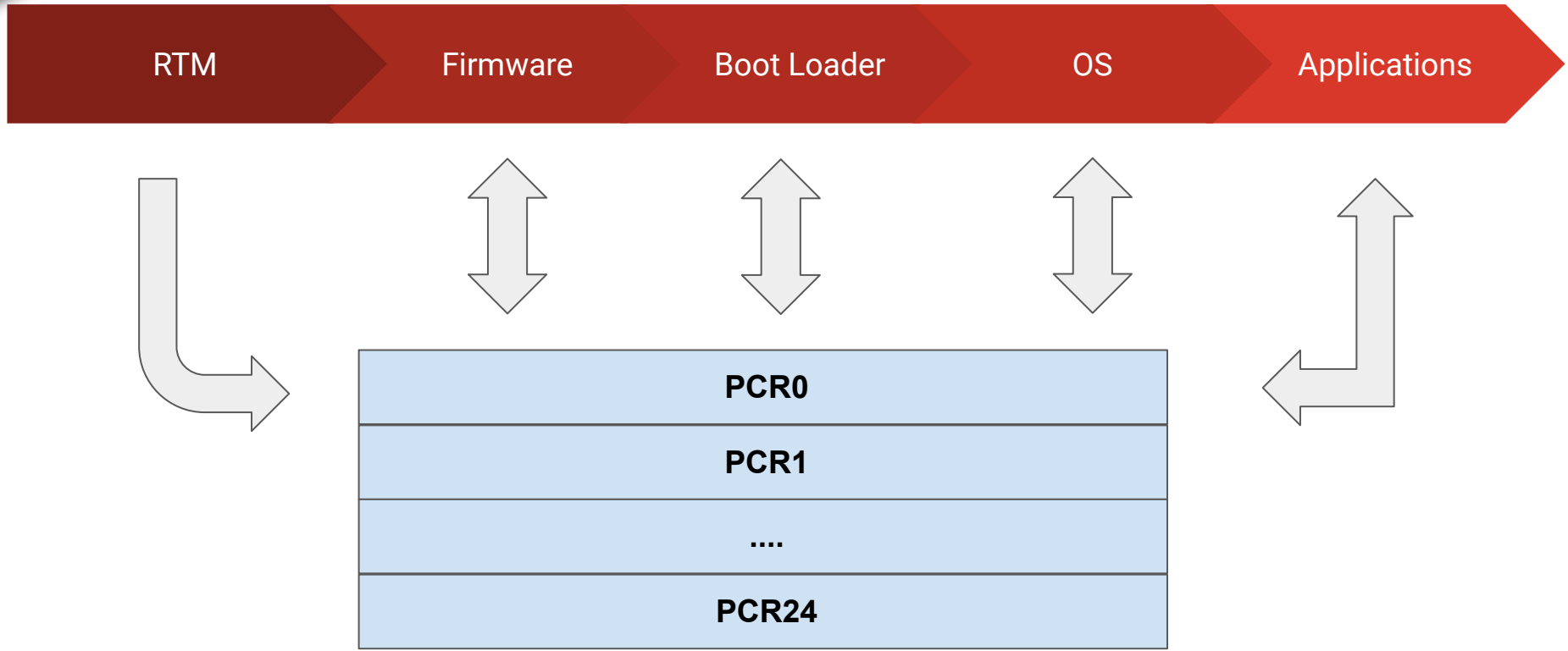
Measured Boot

- Machine state represented by PCRs - Platform Configuration Registers containing cryptographic hashes.
- PCRs can be updated (“Extend” operation) by supplying another hash, but no direct modification is allowed.
- newPCR = HASH(oldPCR || dataToExtend)
- PCRs can only be reset by hardware reset (important)

Source: https://link.springer.com/book/10.1007%2F978-1-4302-6584-9

Measured Boot

- Use PCRs to measure critical components, and if the resulting hashes are incorrect take appropriate action.
- Inconvenient for management - updating measured part of the system forces a change in the verification software.
- On the other hand, Secure Boot only requires user to sign the updated component.



Measured Boot

- On each measurement UEFI updates an event log with object names (file paths) and digests used for the Extend operation.
- One can later compare the log entries against a database of expected values.
- Software can replay the extend operations and confirm log authenticity against signed PCR values. (Quote operation)

Measured Boot

- Currently FreeBSD can’t extend PCRs on its own.
- UEFI measures every binary before passing execution to it - boot1.efi and loader.efi are included in measurements already.
- Loader could be extended to measure kernel and modules too

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Strongswan

- Strongswan is an open source multiplatform IPSEC implementation.
- Tunnels can be established using Internet Key Exchange(IKE) protocol.
- Authentication can be based on certificates or PSK. (Pre-shared key)
- In this case authentication payload is signed with private part of the key bound to certificate.

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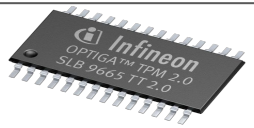
Strongswan - IKE

Signing request with proper authentication

Encrypted digest



private key

TPM

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Prerequisites

- TPM 2.0 FreeBSD driver
- IBM TSS, a userspace library that can “talk” to the TPM.
- Only a small, one-line patch is needed to make it build on FreeBSD.
- Our patch has not yet been merged on IBM TSS Sourceforge.
- Strongswan patched to work with IBM TSS - pull request is up on Github.

Strongswan

- Strongswan can use private keys stored inside a TPM.
- That key is bound with a certificate to be used during IKE.
- Access protected with a passphrase, either be stored in clear text in configuration file or prompted for.
- Private keys are not leaked even if machine is compromised.
- A discrete TPM is slow, on Infineon SLB9655 signing takes ~0.15s using RSA2048 key.

Strongswan

- An excerpt from swanctl config file that links a private key from TPM with a certificate.

```
secrets {
        token_example {
                handle = 0x8XXXXXX # Handle that identifies the key
                pin = "password"   # Optional passphrase
        }
}
```

Acknowledgements

- Stormshield - initiators and sponsors of entire research and development
- Simon J. Gerraty (sjg@) and Juniper - for fruitful and vivid cooperation around the libsecureboot and Veriexec

Questions