Verified Boot and Free Software: Reconciling Freedom and Security

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Introducing Verified Boot and Related Issues

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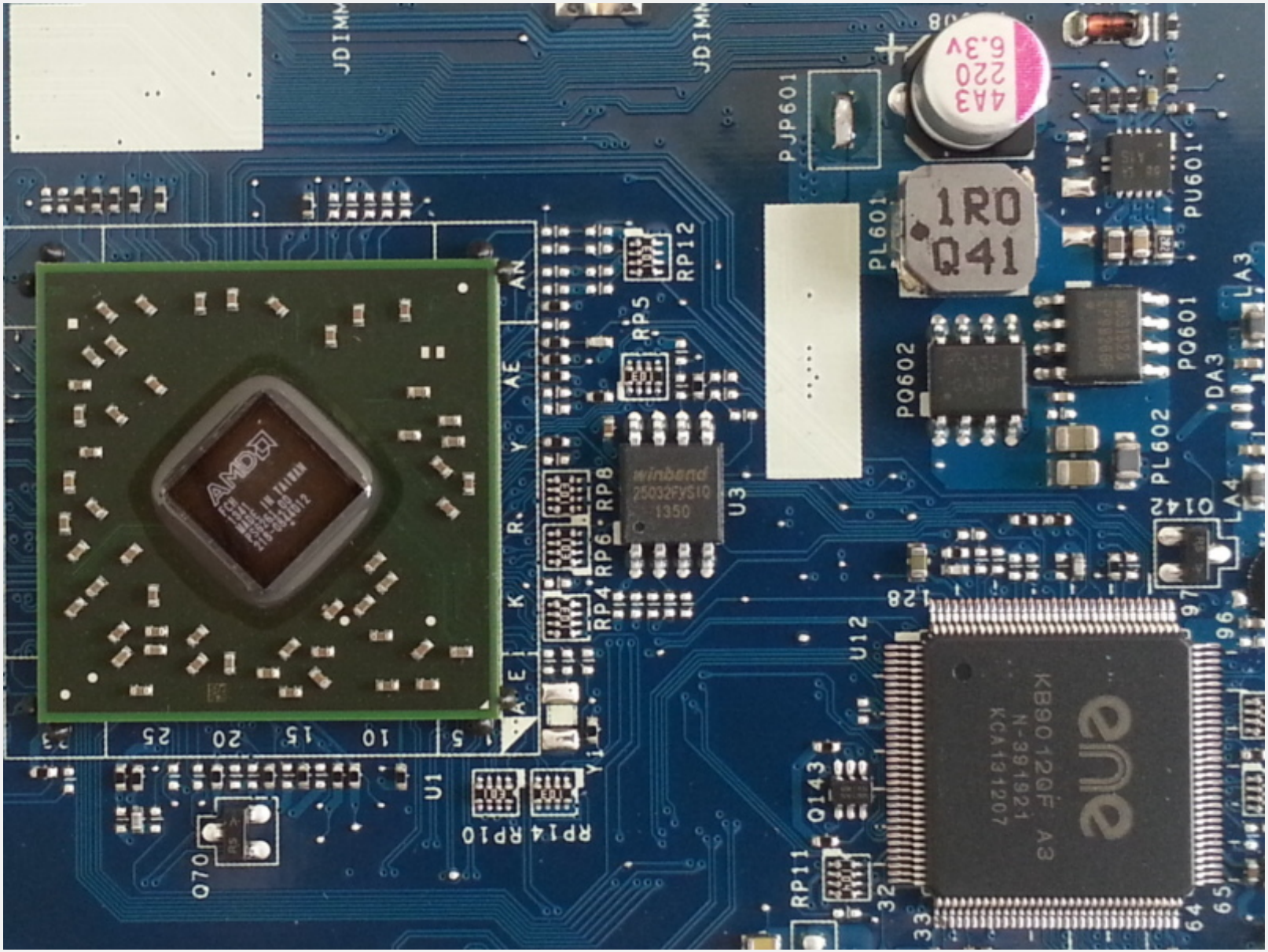
Bootup Process

BIOS History

Basic Input/Output System:

- 1980s:
  - Basic hardware initialization
  - Operating system load
  - BIOS interrupt calls (used by CP/M, DOS)
  - Purpose: hardware abstraction
  - Read-only memory
- 1990s:
  - Increasing hardware complexity
  - Drivers in operating systems, initialization only
  - Read/write memory (updates)
- 2000s:
  - Run-time services (SMM/SMI, ACPI)
  - Unified Extensible Firmware Interface (UEFI)
  - Back to hardware abstraction

SPI Flash?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JDIMM
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Q41
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LA3
LA4
Q142
RP12
RP5
RP8
RP6
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winbond
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Q143
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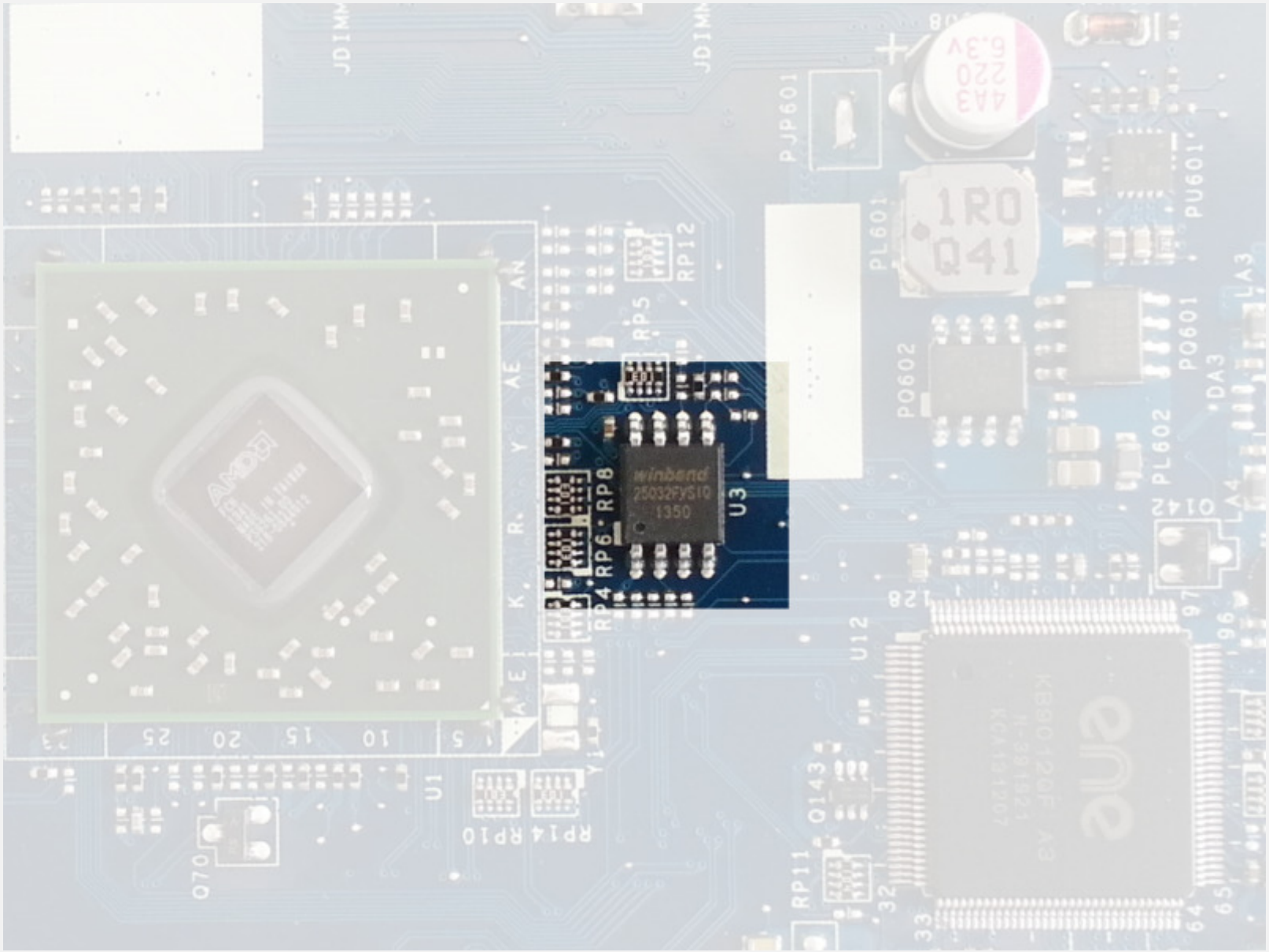
SPI Flash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PO601
PL602
U12
U1
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Q41
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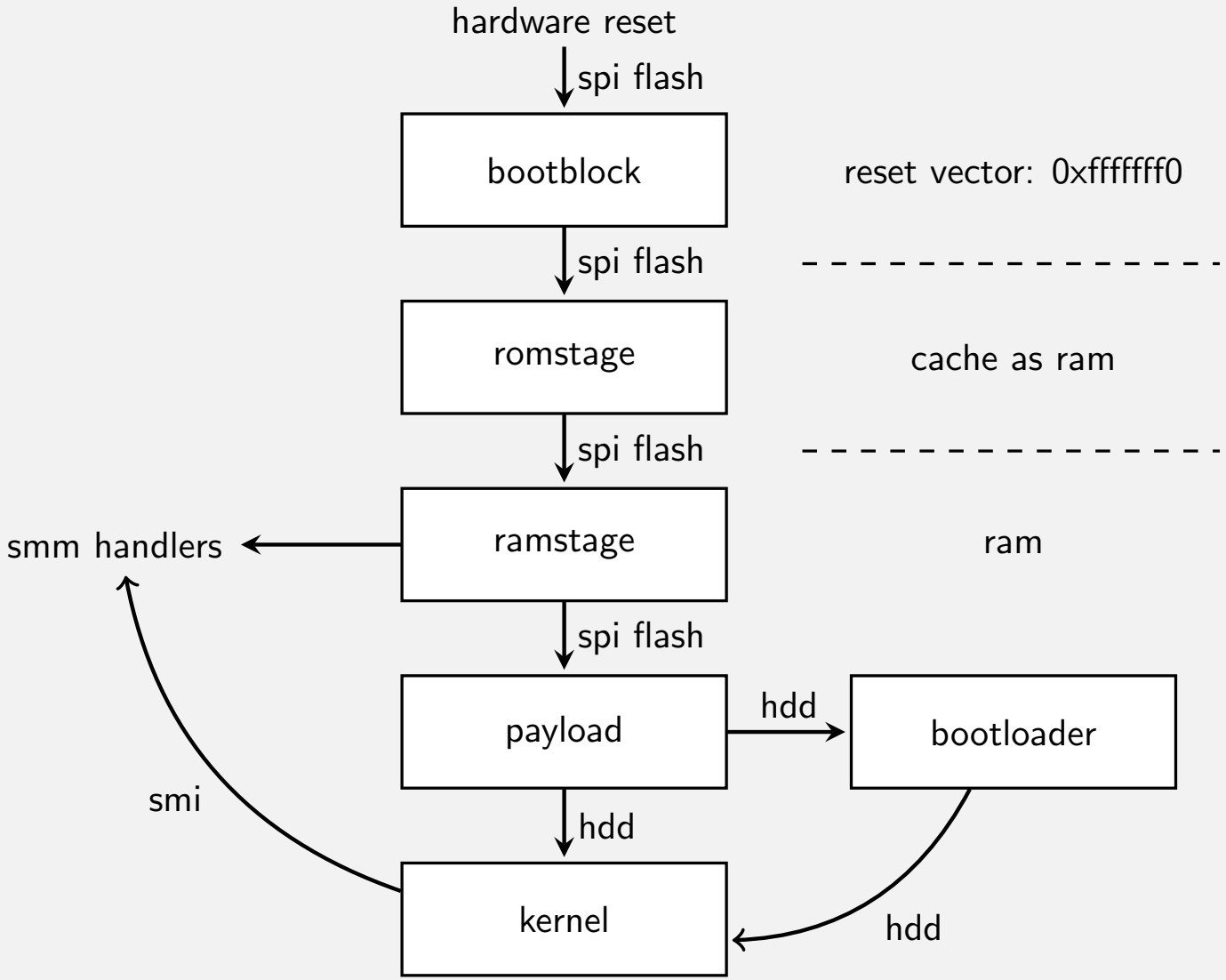
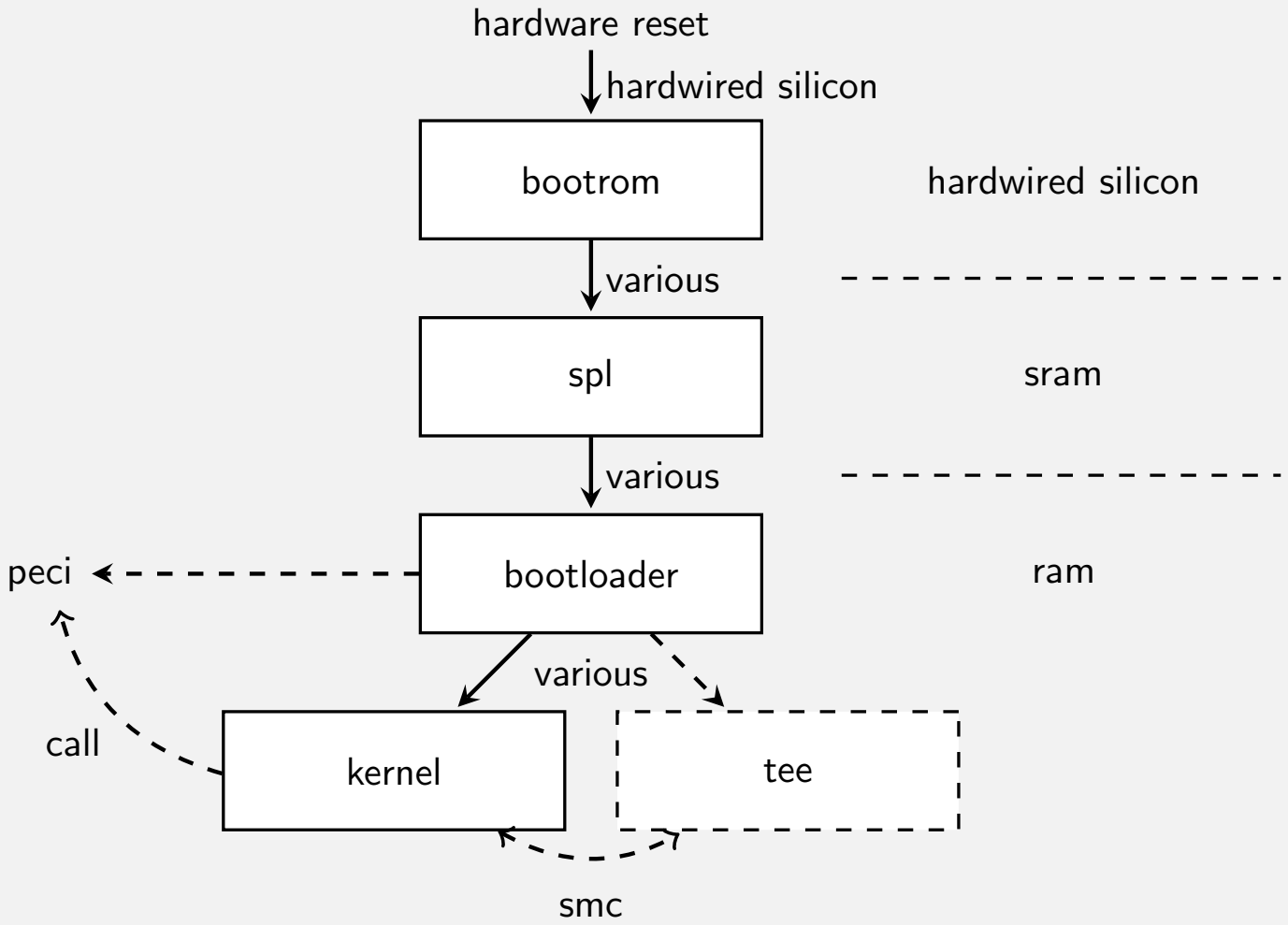
220
6.3V

(Traditional) x86 Bootup Process



ARM Bootup Process



Trusted Execution Environment

Need for trusted run-time software:

- Operating system is flawed
- Privileged operations, hardware access
- Sensitive operations (privacy/security)

Implementing a trusted environment:

- Independent or setup by bootup software
- Cooperation with the platform (e.g. **TrustZone**)
- Privileged mode, interfacing (e.g. SMC)

Introducing Verified Boot and Related Issues

Software Freedom

Freedom and Privacy/Security Considerations and Issues

Bootup software considerations:

- Precedence over the system
- *Runs during the system lifetime*
- *Loads the TEE*
- Great control, abilities and user data access
- Hardware initialization knowledge

Associated issues:

- Trust and control:
  - Audit (weaknesses, backdoors)
  - Bug fix (delays, EOL)
  - User modification
- Restrictions
- Access to knowledge

Basic Freedoms

Guarantees: basic freedoms

0. Run for any purpose
1. Study and modify
2. Redistribution
3. Redistribution of modifications

Free software is a hard requirement!

Free Bootup Software

Bootrom (ARM):

- Read-only: **hardwired**
- Always **non-free** (hardware design)

Free bootup software projects:

- Coreboot
- U-Boot, Barebox
- Libreboot

Usual non-free components:

- **x86**: Option ROM/VGA BIOS, CPU microcodes
- **Intel x86**: FSP, MRC, ME
- **AMD x86**: IMC, SMU, PSP
- Various firmwares (xHCI, ethernet, . . .)

Introducing Verified Boot and Related Issues

Bootup Software Verification

Early Software Verification

Security approaches distinction:

- Verified boot: to boot or not to boot
- Measured boot: state indication

Verified boot rationale:

- Read/write bootup software
- Attack surface, compromisation
- Chain of trust up to the system, handlers

Design implications:

- Early bootup software must be trusted
- Next stage validation: signatures
- Read-only signatures

Early Attempts at Integrity Preservation

Pin-driven write-protect:

- Easy to find out
- Flashrom board enables

flashrom/board_enable.c:

```
static int intel_piix4_gpo27_lower(void)
{
    return intel_piix4_gpo_set(27, 0);
}
```

Platform-based approaches:

- Platform SPI access/write disable
- Protected Ranges (PRx)

Pitfalls:

- Privileged access (SMM)
- Internal controller access (ME, IMC)
- External access
- Platform-specific logic

UEFI and Secure Boot

Secure boot implementations:

- Bootloader or kernel verification
- Ships with verification keys
- Assumes it's not compromised

User control:

- Secure boot disable?
- Replacing keys?

(Actually) Verified Boot

Strong root of trust:

- Keys in OTP memory
- Bootrom enforcing verification

Motivations:

- Multiple read/write storage
- Reliable root of trust

Implementations:

- ARM platforms
- Intel Bootguard
- Intel TXT ACM (dynamic root of trust)

Introducing Verified Boot and Related Issues

Software Freedom Issues

Incompatibility with Free Software

Issues for freedom:

- Free bootup software is **impossible**!
- Free TEE software is **impossible**!
- *Free kernel is* **impossible***!*

Implications for privacy/security:

- No control, no choice for trust
- (Un)intentional weaknesses
- Ability to compromise the system, exfiltrate data:
  - At boot time
  - At run time: TEE, SMM/SMI, ACPI, PECI

Neither freedom, nor privacy/security :(

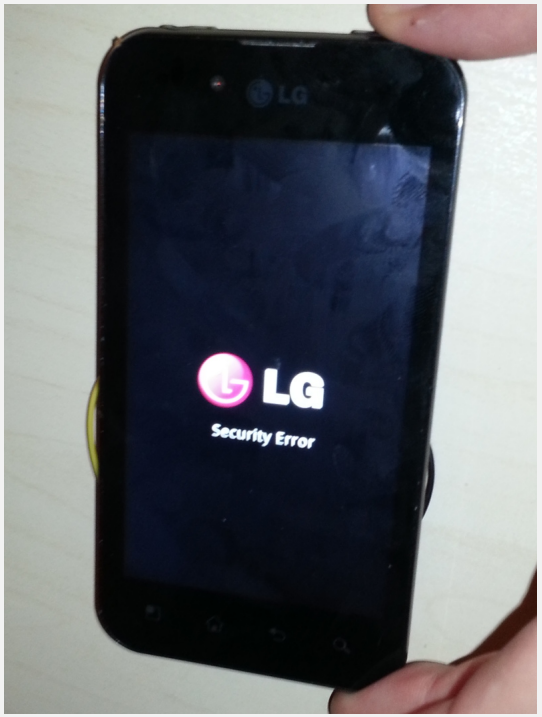
(Barely) Undercover Motivations

Usual scenario (Android):

- Verified SPL and bootloader
- Verified TEE
- Chain of trust break

Story time:

- LG Optimus Black
- Google Pixel C



Rationale? Anyone? It's pronounced **DRM**.

Tivoization and Licenses

Tivoization:

- Free, copyleft bootup software
- Modified versions release
- Signed binaries for verified boot

Case study:

- Samsung Galaxy Tab 2
- X-Loader SPL

Classification	Model	Version	Source Code	Announcement	Inquiry
Mobile Phone	GT-P5100	P5100XXDN...	GT-P5100_JB_Opensource_Update3.zip		
Mobile Phone	GT-P5100		GT-P5100_JB_Opensource_Update2.zip		
Mobile Phone	GT-P5100		GT-P5100_JB_Opensource_Update1.zip		
Mobile Phone	GT-P5100		GT-P5100_ICS_Opensource_Update1.zip		
Mobile Phone	GT-P5100		GT-P5100_ICS_Opensource.zip		

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x-loader/SecureBootSign.pl:

```
$RemoteServer1 = "10.254.124.52";
$RemoteServer2 = "10.90.13.36";
[...]
$handle = IO::Socket::INET->new("$RemoteServer:80") or $newerr=1;
$handle->send("GET http://$RemoteServer/SigningKey.php?model=$modelname&type=
      $runtype&filename=$input_filename&filepath=$ftp_sub_path&prefix=$prefix&
      viewtype=$viewtype&ppa=$config_filename HTTP/1.0");
```

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Oh, the irony!

Licenses:

- GPLv3

All About the Main CPU?

Software is everywhere:

- Main processor: Bootup, TEE, System
- Management processors: ME, IMC, SMU, BMC...
- Auxiliary processors: GPU, VPU, DSP...
- Controllers: EC, xHCI, multimedia, battery...
- Peripherals: Wi-Fi, bluetooth, GPS, webcam...

Verified boot:

- Main processor: **common** (ARM)
- Management processors: **common**
- Auxiliary processors: **increasing** (GPUs)
- Controllers: **uncommon**
- Peripherals: **uncommon**

Freedom and privacy/security everywhere?

Reconciling Freedom and Security

Reconciling Freedom and Security

General-Purpose Possibility

Coreboot, GRUB and PGP

Verified boot with free software example:

- Free bootup software (Coreboot)
- Payload with PGP verification (GRUB)
- Storage set read-only (or hidden)
- External access to storage

Platform assumptions:

- No signature verification from bootrom
- Ability to lock the storage (access/write/regions)

Possible with non-Bootguard x86 platforms!
(with Coreboot support)

SPI Flash Write-Protect

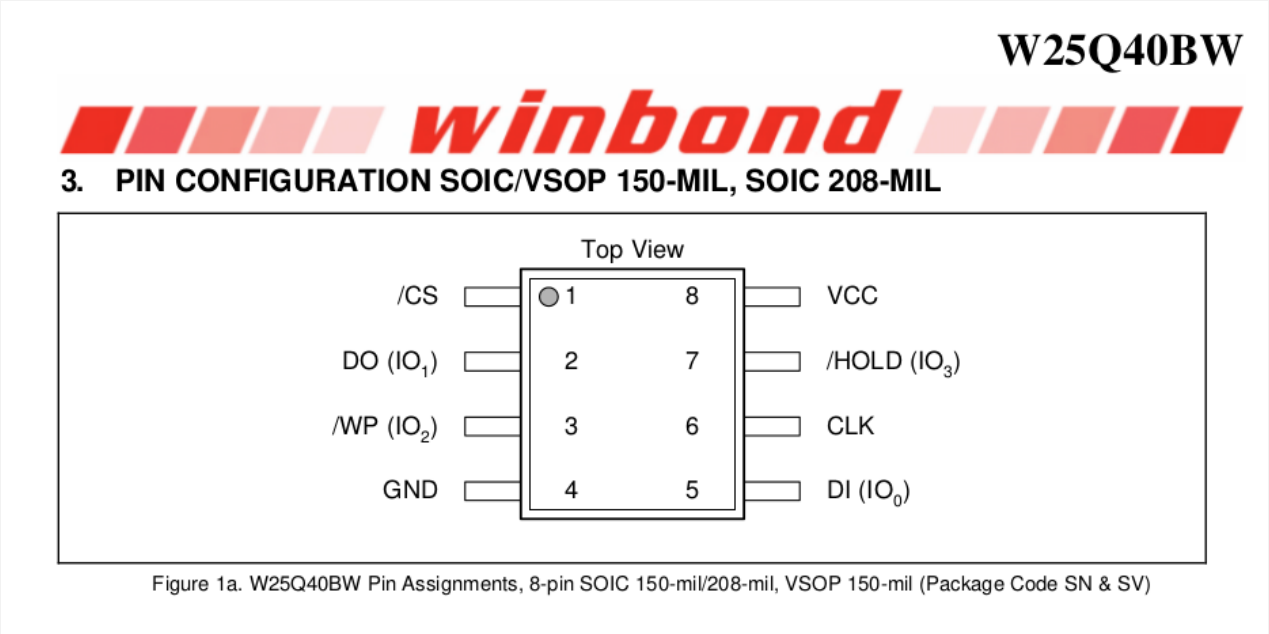


Figure 1a. W25Q40BW Pin Assignments, 8-pin SOIC 150-mil/208-mil, VSOP 150-mil (Package Code SN & SV)

Write-protect ($\overline{WP}$) pin:

- Reliable root of integrity!
- Physical switch
- Solder it to ground

Reconciling Freedom and Security

CrOS Security Model and Devices

Design Guidelines

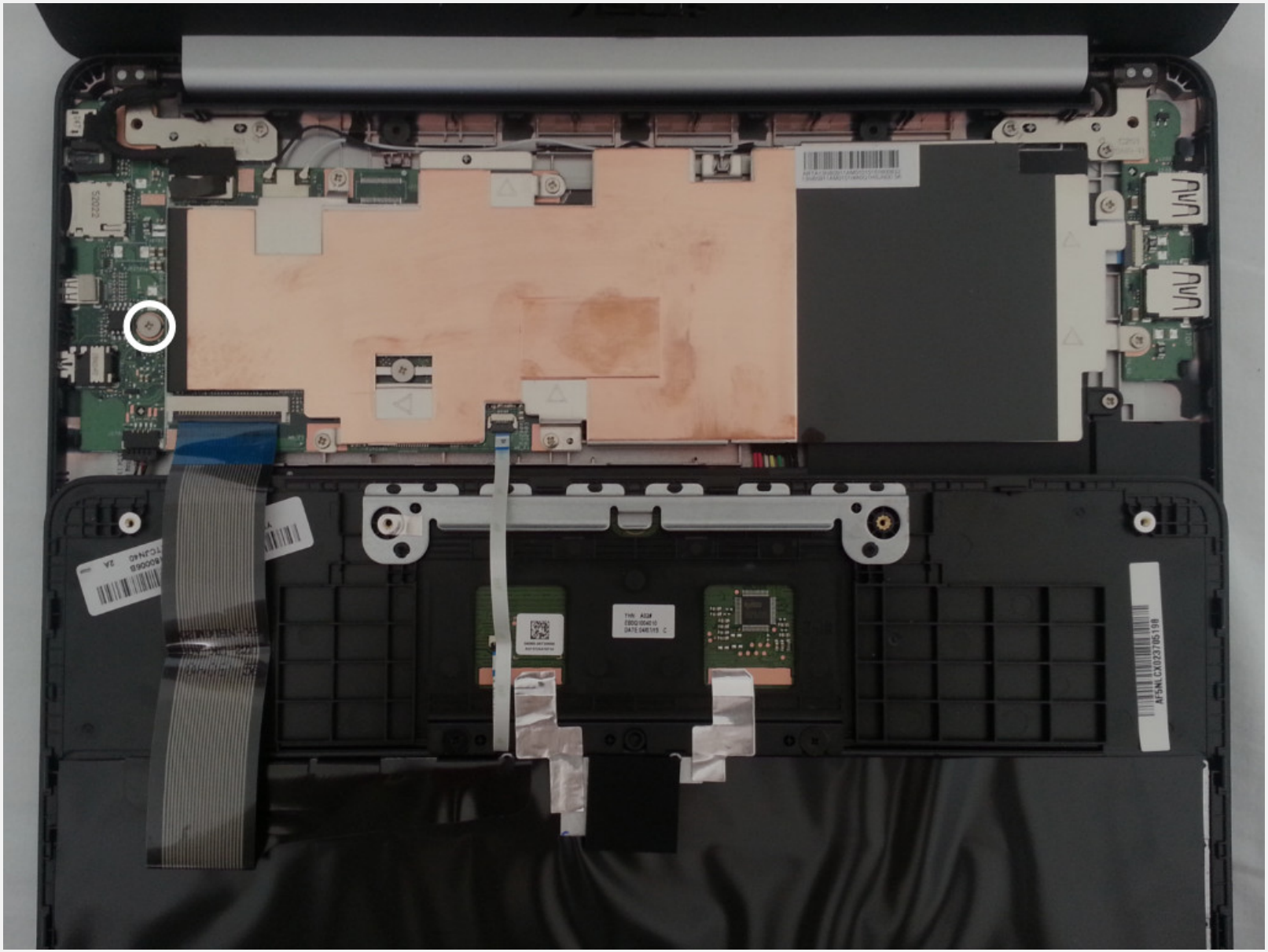
CrOS security design:

- Reliable, scalable verified boot for CPU and EC
- Does not cover external access (evil maid)
- Free software, user-friendly

Chain of trust:

- SPI flash write-protect root of trust
- The screw: write-protect switch
- RO early stages, keys and recovery
- RW (verified) next stages and kernel

The Screw



Verified Boot Software

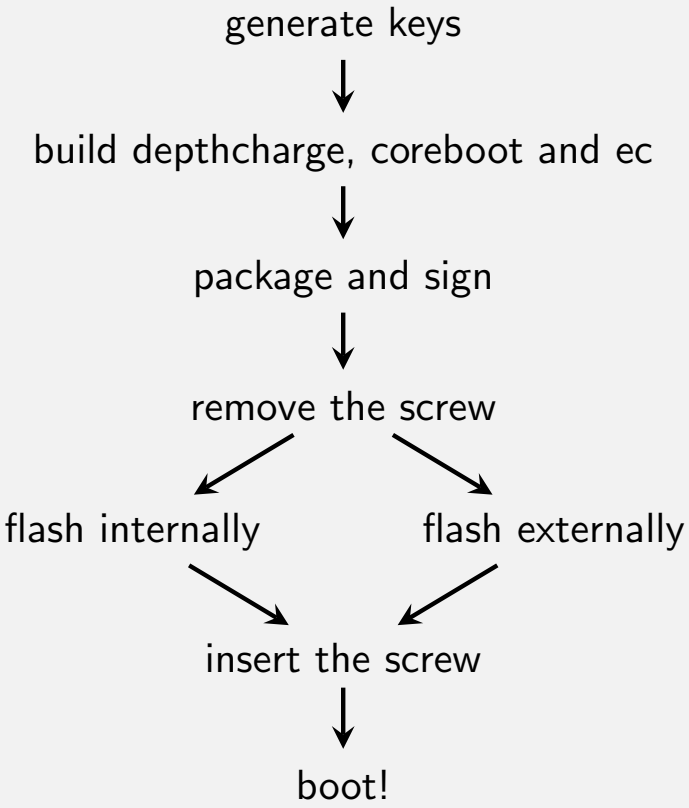
Software components:

- Bootup software: Coreboot
- Payload: Depthcharge
- Verified boot: Vboot
- EC firmware: Chrome EC

Boot modes:

- Normal mode
- Recovery mode
- Developer mode

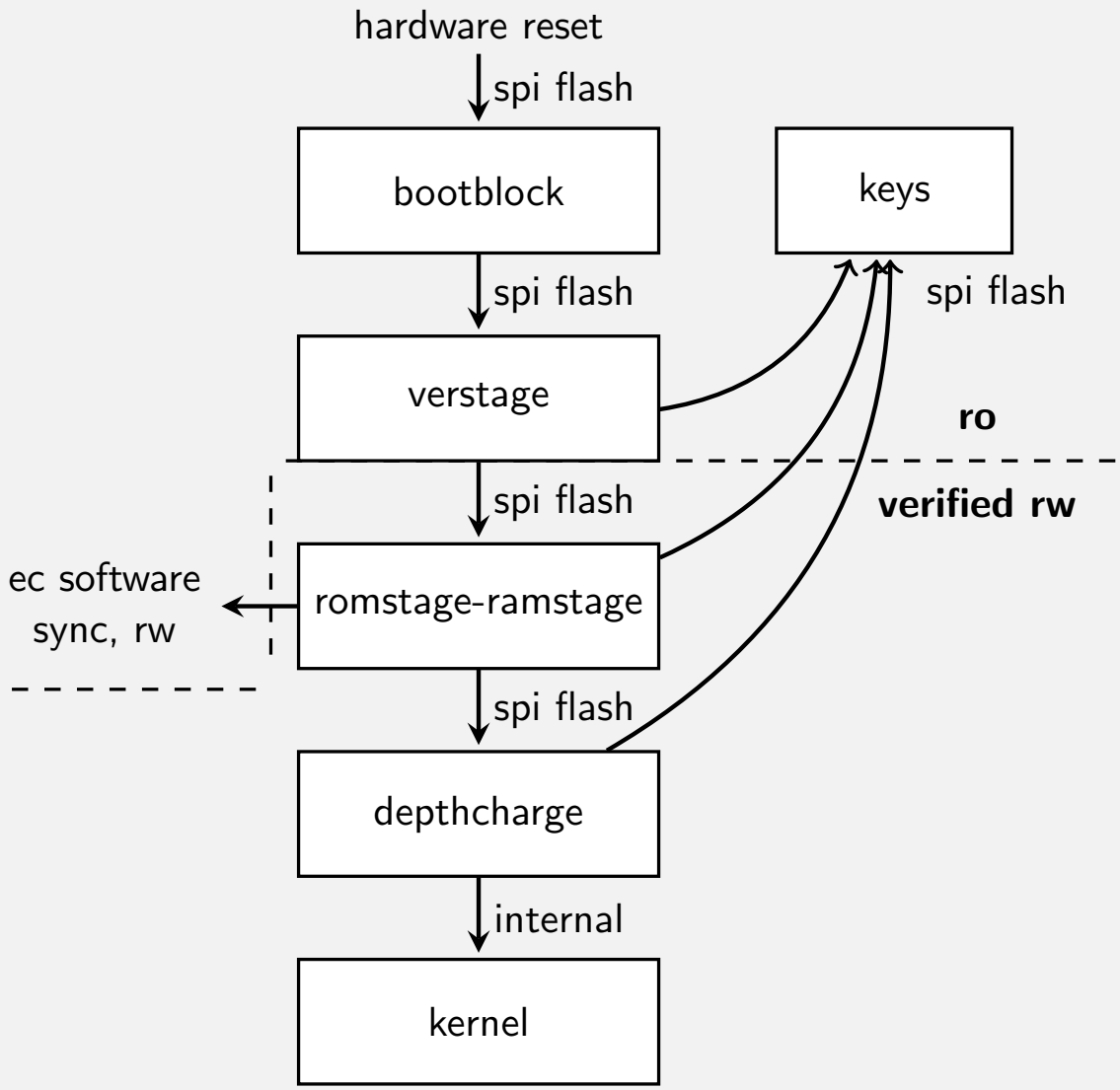
Replacing software and keys:



Normal Boot

Boot path:

- RO bootblock
- RO verstage
- RW next stages
- RO to RW EC
- Internal kernel
- No interaction



Recovery Boot

Trigger:

- Verification error
- User request

Boot path:

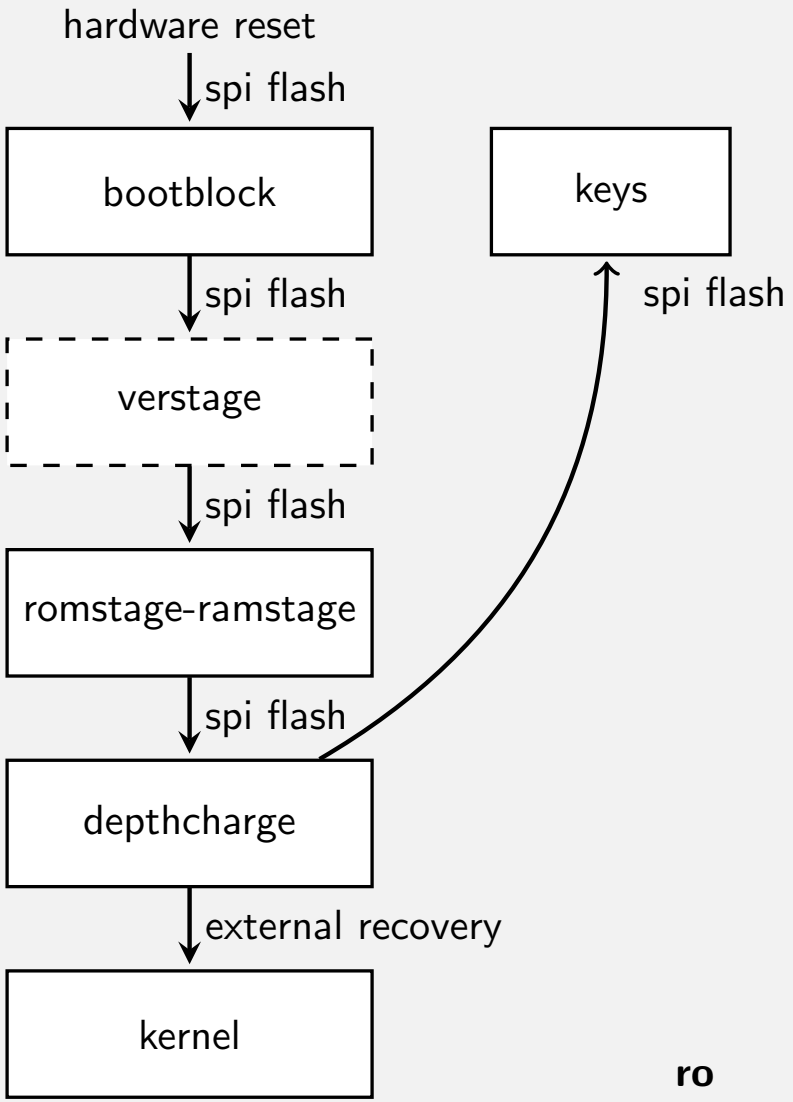
- RO only

Boot media:

- External recovery
- Recovery keys

Recovering:

- Instructions



Developer Boot

Enable:

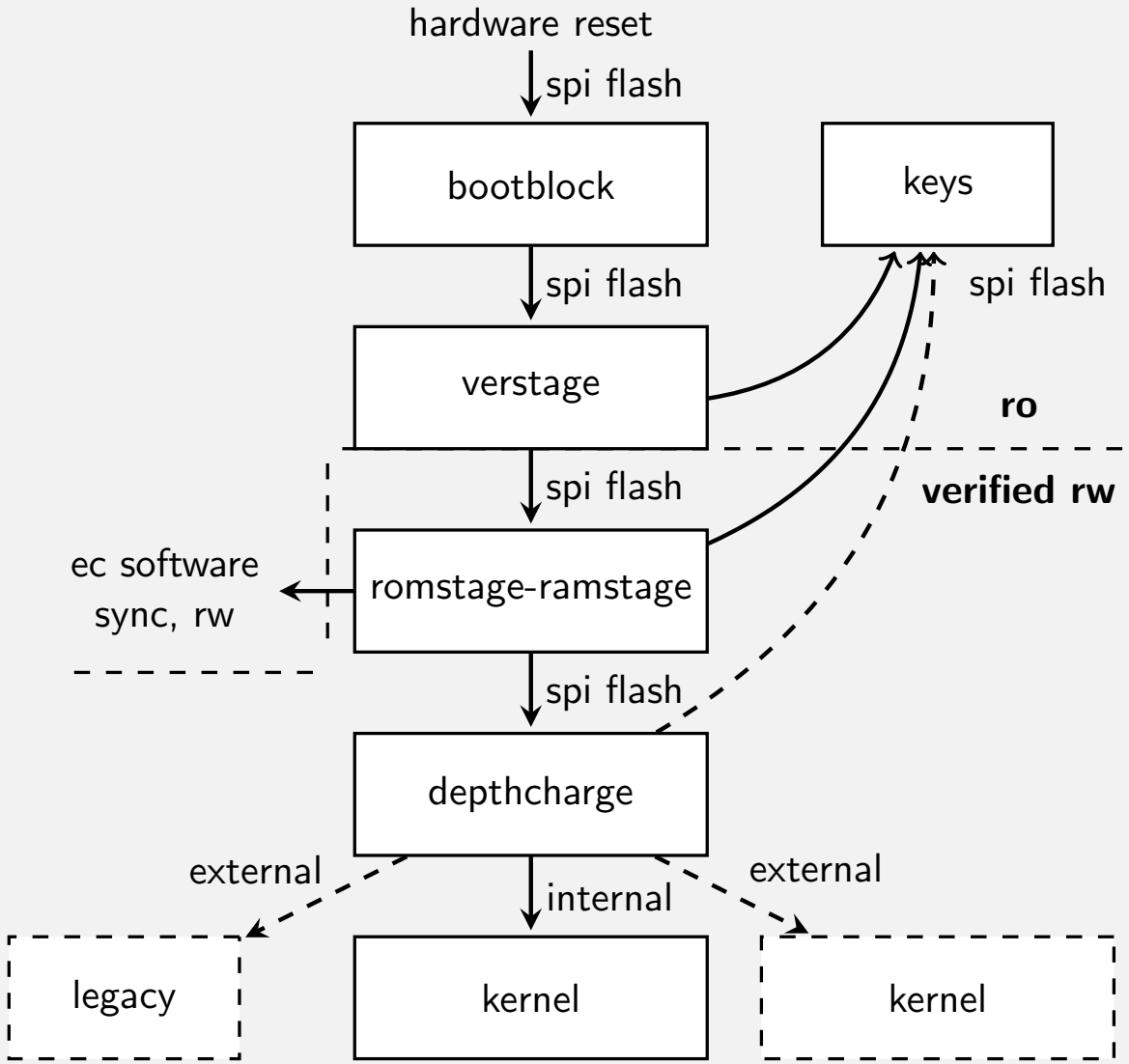
- Recovery mode
- Wipes data
- CrOS root
- Crossystem

Boot path:

- RO to RW
- Kernel verification

Boot media:

- Internal
- External
- Legacy



Devices

Hardware design constraints:

- SPI flash and the screw
- TPM
- Servo debug connector

Chromebooks, Chromeboxes, Chromebases, Chromebits

Platforms:

- **x86**: Intel Sandybridge, Haswell, Broadwell, Baytrail, Skylake
- **Signed ARM**: Samsung Exynos
- **Unsigned ARM**: Rockchip RK3288, nVidia Tegra K1

Unsigned ARM devices are great for freedom and privacy/security!

Community Support

CrOS developers community approach:

- *CrOS firmware team* history
- Friendly, helpful developers
- Contributions welcome, patch review
- Source code: `https://chromium.googlesource.com`

Community software:

- Upstream Coreboot support
- Libreboot support: build, images, documentation
- Upstream kernel support

Thank-You!

Questions?

Reference, interesting reads:

- https://www.chromium.org/chromium-os/chromiumos-design-docs
- https://blog.cr4.sh/2016/06/exploring-and-exploiting-lenovo.html
- https://coreboot.org/
- https://libreboot.org/
- https://firmwaresecurity.com/
- https://mjg59.dreamwidth.org/