Arms Race

The story of (in)-secure bootloaders

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Mobile Device Ecosystem

- Players
  - Device Manufacturers (Samsung, Apple, Qualcomm)
  - Service Providers (AT&T, Verizon)
  - Device “Owners”

The Need to Study Bootloaders

- Break the Lockdown
  - Do not have root access

    Installing unofficial apps
  - Can not run non-stock kernels

    Loading customized kernels
  - Can not replace boot loaders

    Helping break the layers above

What this Talk is about

- Multiple case studies of
  - Do not have root access

    Installing unofficial apps
  - ~~Can not run non-stock kernel~~

    Loading customized kernels
  - ~~Can not replace boot loaders~~

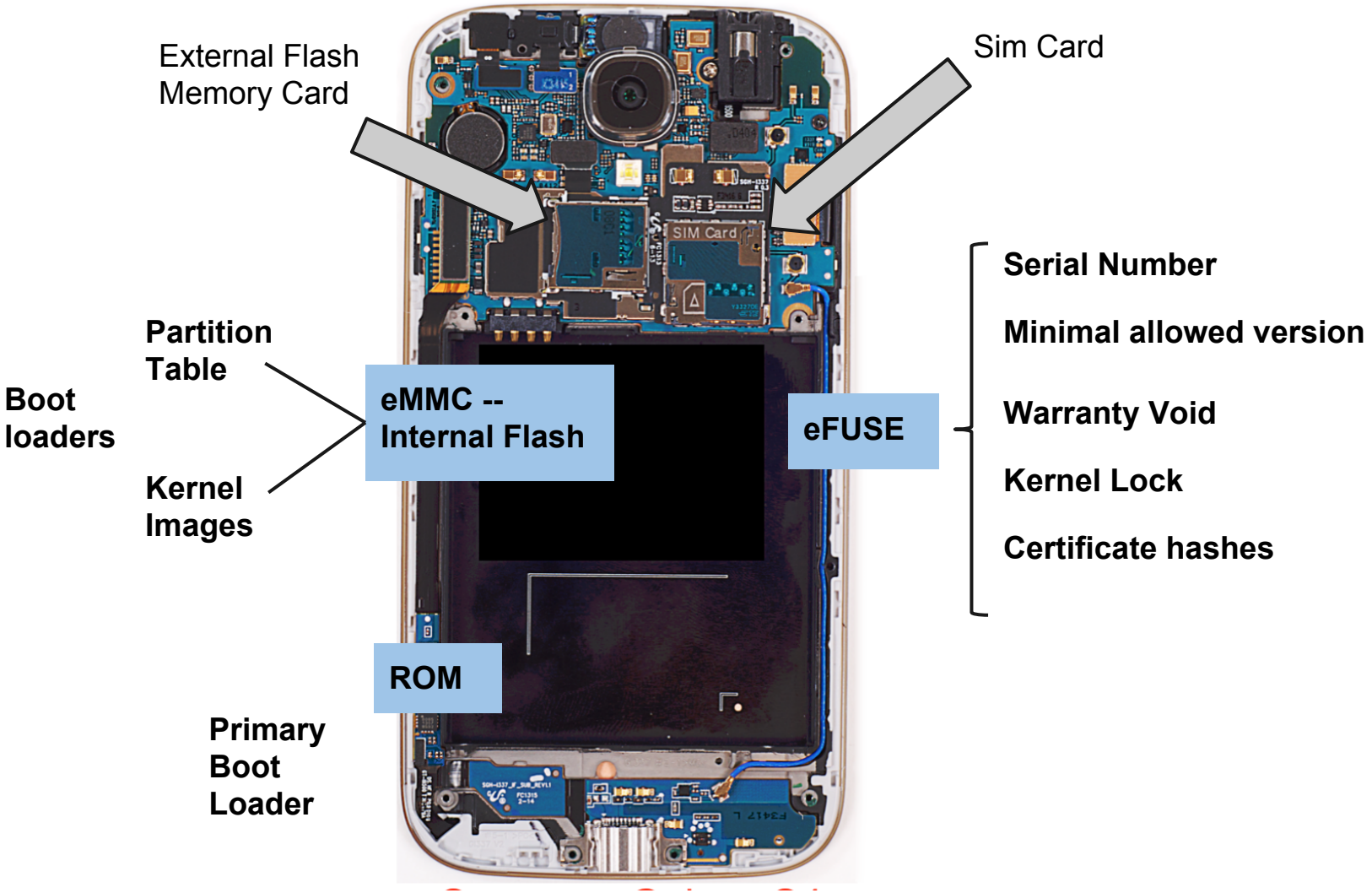
    Replacing bootloaders

Disclaimers

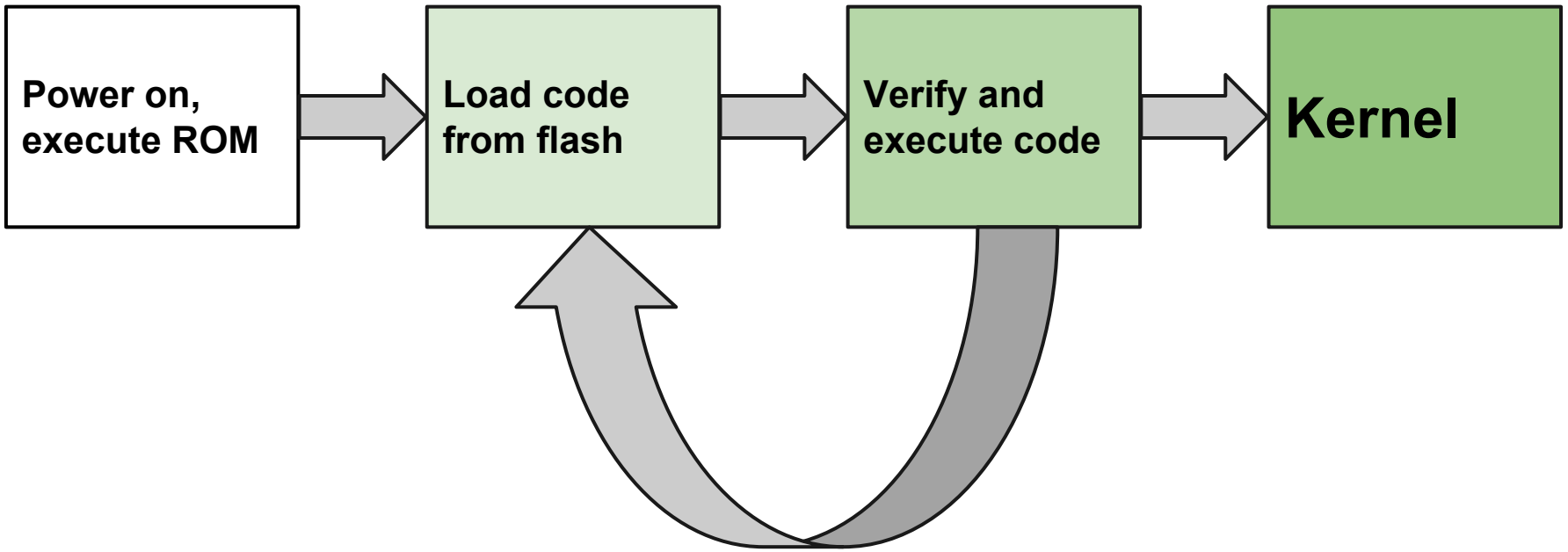
- No newly discovered bootloader flaws.
- All bugs have been patched.
- All bugs were found independently by us.
  - one was disclosed by others first.
- Then why make this talk?
  - Bootloader security is unique (and fun).

Why Make This Talk?

- Unique aspects of bootloader security
  - Severe time-pressure on product delivery
  - Threat source
    - From device owners
    - Physical access
  - Some mistakes found were unconventional

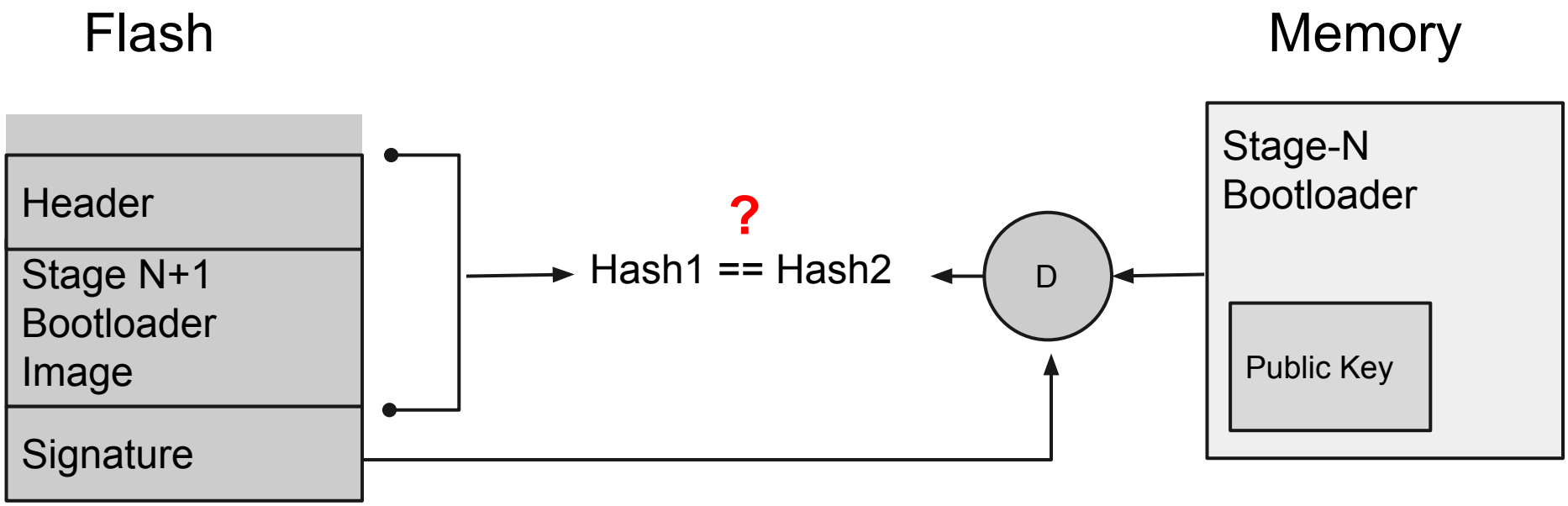

External Flash Memory Card
Sim Card
SIM Card
Partition Table
Boot loaders
Kernel Images
eMMC -- Internal Flash
eFUSE
Serial Number
Minimal allowed version
Warranty Void
Kernel Lock
Certificate hashes
ROM
Primary Boot Loader

Boot Flow Overview



Sometimes many stages of code must be loaded

Bootloader Image Verification (simplified)



Case #1

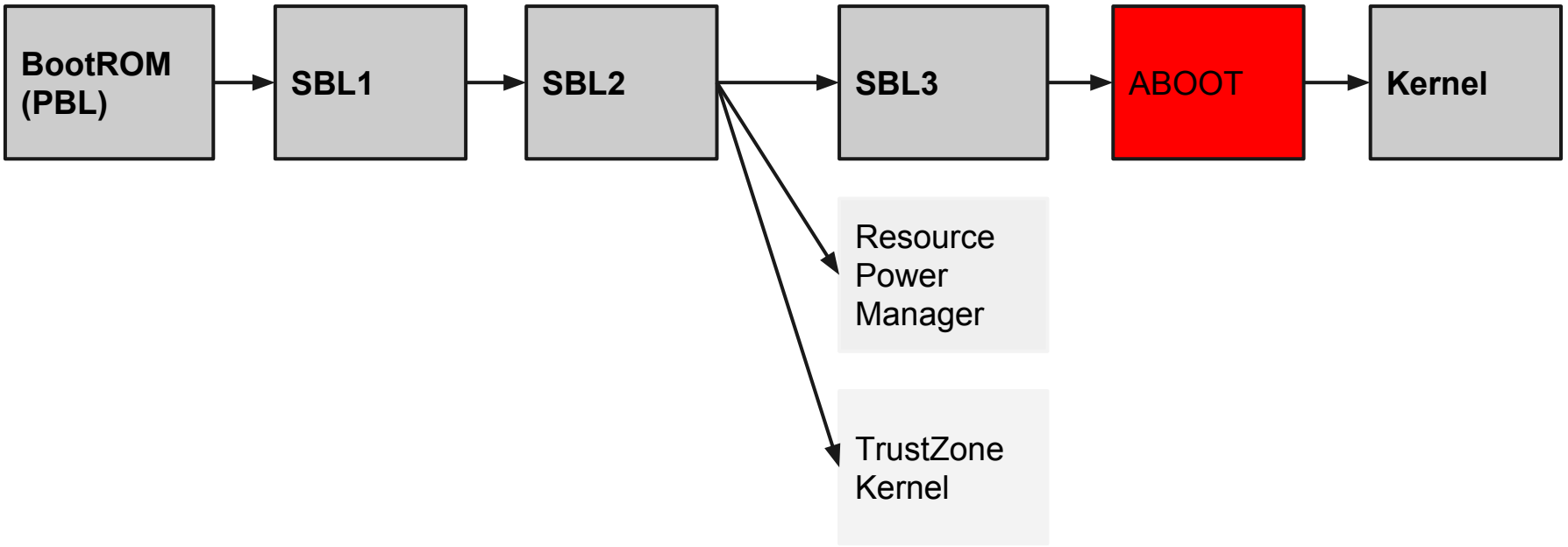
Samsung Galaxy S3

- Released in mid-2012
- Based on the Qualcomm MSM8960 chipset

http://static.trustedreviews.com/94/000023989/3659/s3fronts.jpg

Goal: Boot a customized kernel image

S3 Boot Flow

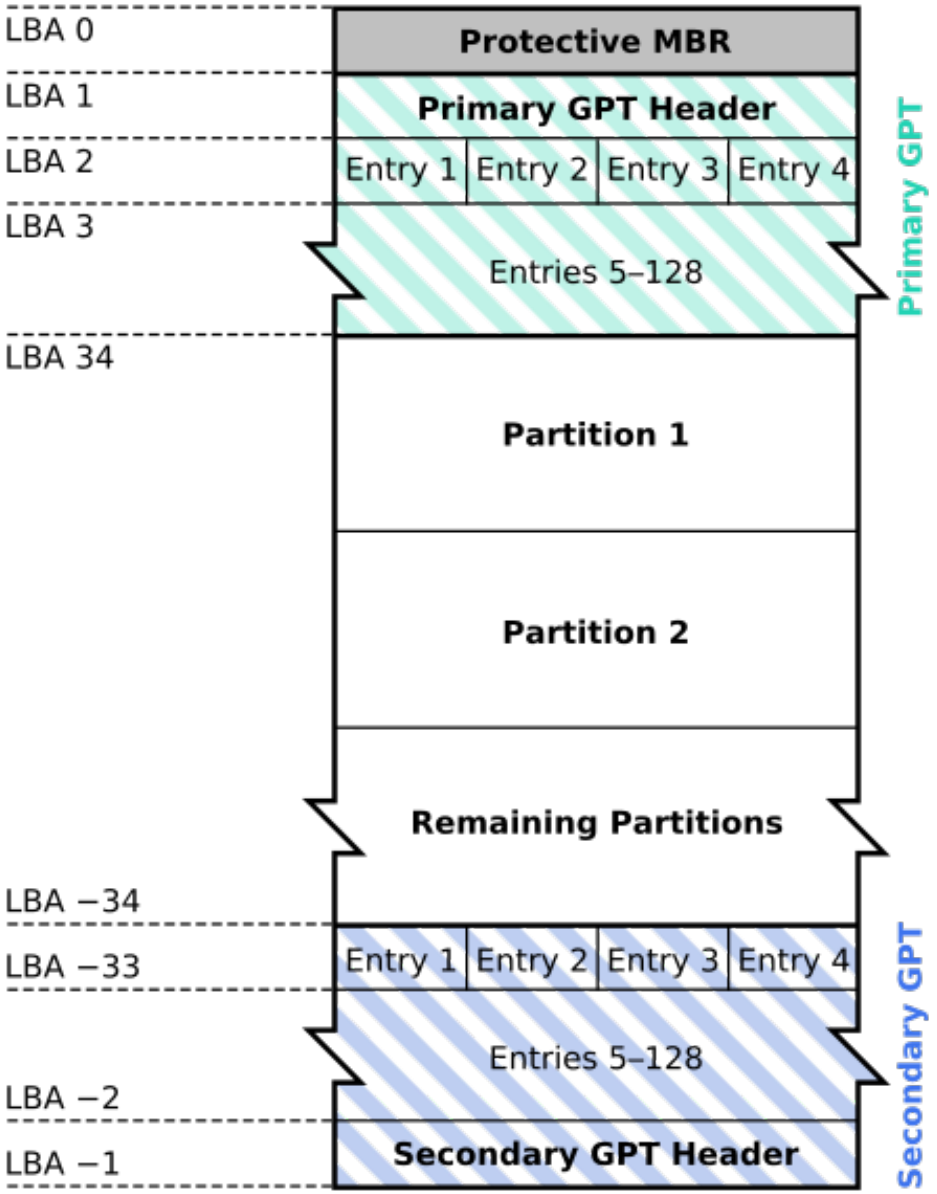

BootROM (PBL)
SBL1
SBL2
SBL3
ABOOT
Kernel
Resource Power Manager
TrustZone Kernel

➔ Kernel image is loaded twice by ABOOT

First load the code for execution

Second load for verification

GUID Partition Table Scheme



Loading and Verification

```
for (p in partitions) {
        if (strcmp(p.name, “boot”) == 0) {
                load_partition_to_memory(p)
                break
        }
}
```

Loading

Verification

```
for (p in partitions) {
        if (stricmp(p.name, “boot”) == 0) {
                if (load_and_verify_signature(p))
                        boot_kernel()
                else show_error()
        }
}
```

Notice any difference?

```
for (p in partitions) {
        if (strcmp(p.name, “boot”) == 0) {
                load_partition_to_memory(p)
                break
        }
}
```

Loading

Verification

```
for (p in partitions) {
        if (stricmp(p.name, “boot”) == 0) {
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}
```

Notice any difference?

```
for (p in partitions) {
      if (strcmp(p.name, “boot”) == 0) {
            load_partition_to_memory(p)
            break
      }
}
```

Loading

strcmp:
case sensitive

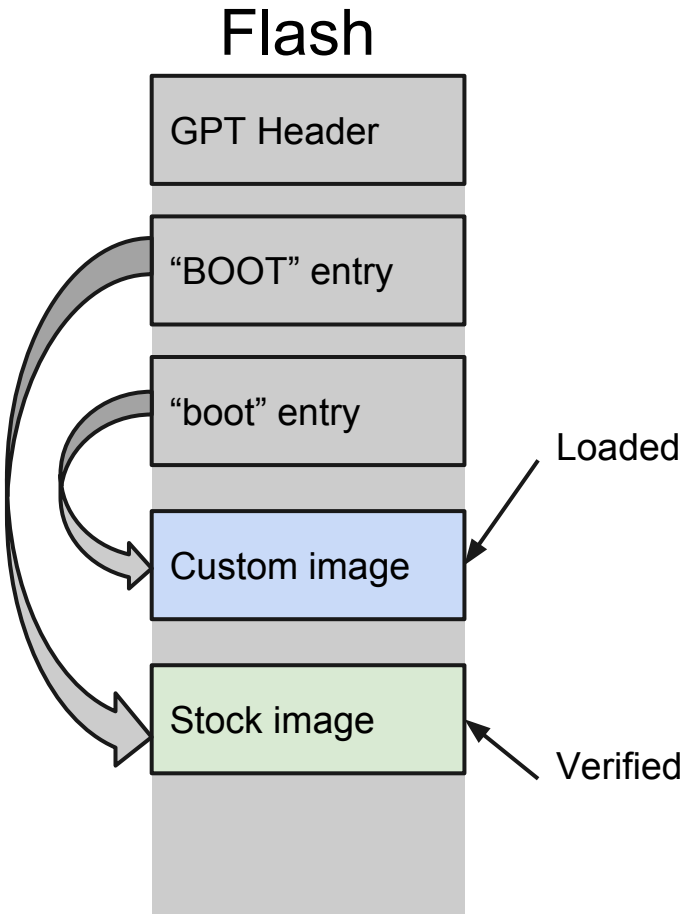
stricmp:
case in-sensitive

Verification

```
for (p in partitions) {
      if (stricmp(p.name, “boot”) == 0) {
            if (load_and_verify_signature(p))
                  boot_kernel()
            else show_error()
      }
}
```

Exploit:

Edit the GPT and add a “BOOT” partition before the “boot” partition



Case Closed

Patched when S3 was updated to Android 4.1.

They altered the signature verification to only load the kernel image once.

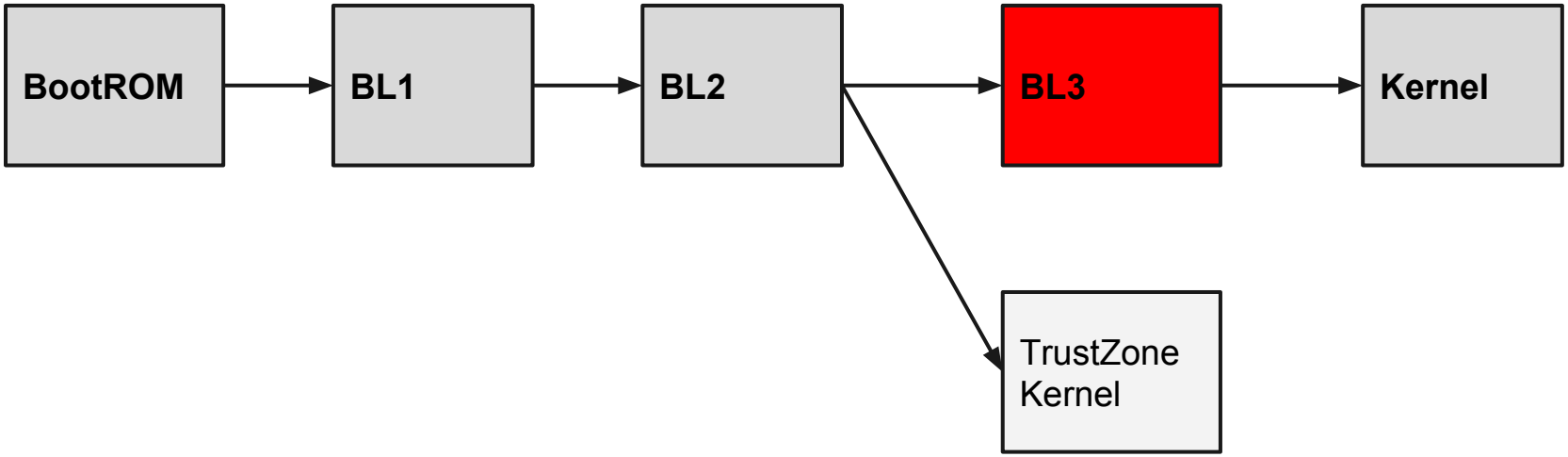
Case #2

Samsung Galaxy Note II

Released in Fall 2012
Based on Samsung's Exynos 4 Quad SoC

Goal: Boot a customized kernel image

Exynos 4 (Note II) Boot Flow



Kernel Load

```
// flash_read(mem_dst, disk_src, size)

flash_read(&boot_header, ptn_start, HEADER_SIZE);
if (memcmp(boot_header.magic, "ANDROID!") == 0) {
    // load kernel to 0x40008000, verify it
    // copy ramdisk to 0x42000000
}

Later...
jump to 0x40008000
```

Some Secret !

```
flash_read(&boot_header, ptn_start, HEADER_SIZE);
if (memcmp(boot_header.magic, "ANDROID!") == 0) {
    // load kernel to 0x40008000, verify it
    // copy ramdisk to 0x42000000
} else {
    flash_read(0x40008000, ptn_start, 0x800000);
}
Later...
jump to 0x40008000
```

Likely a debug branch

```
flash_read(&boot_header, ptn_start, HEADER_SIZE);
if (memcmp(boot_header.magic, "ANDROID!") == 0) {
    // load kernel to 0x40008000, verify it
    // copy ramdisk to 0x42000000
} else {
    flash_read(0x40008000, ptn_start, 0x800000);
}
Later...
jump to 0x40008000
```

A small victory!

- That “else” branch lets us run unsigned code
- Custom kernel booting was made possible

A small victory!

- That “else” branch lets us run unsigned code
- Custom kernel booting was made possible
- But … **the load action is very primitive**

Need to develop a customized kernel loader

Case #2.1

Samsung Galaxy Note II

Can we modify the early bootloader stages?

Goal: to simplify custom kernel loading

Changing the bootloader

Problem: Bootloader is signed

Any modification breaks the signature

How to solve this?

BL1 Verification

- BL1 is verified by BootROM
- BootROM uses a fixed key inside the CPU
- How can this help?

BL1 Verification

- BL1 is verified by BootROM
- BootROM uses a fixed key inside the CPU.
- **The same key was used across all CPUs of the same model.**

Jackpot

- The ODROID-X hobby board shipped with a BL1 that didn't check the signature of the second stage (BL2).

Make a Custom Bootloader

- If we glue their BL1 with a patched BL2/3 then we can boot a custom kernel.

- Custom bootloader created!

The BootROM is still able to validate the BL1, and then the custom BL2/3 will run without checking the signature of future stages

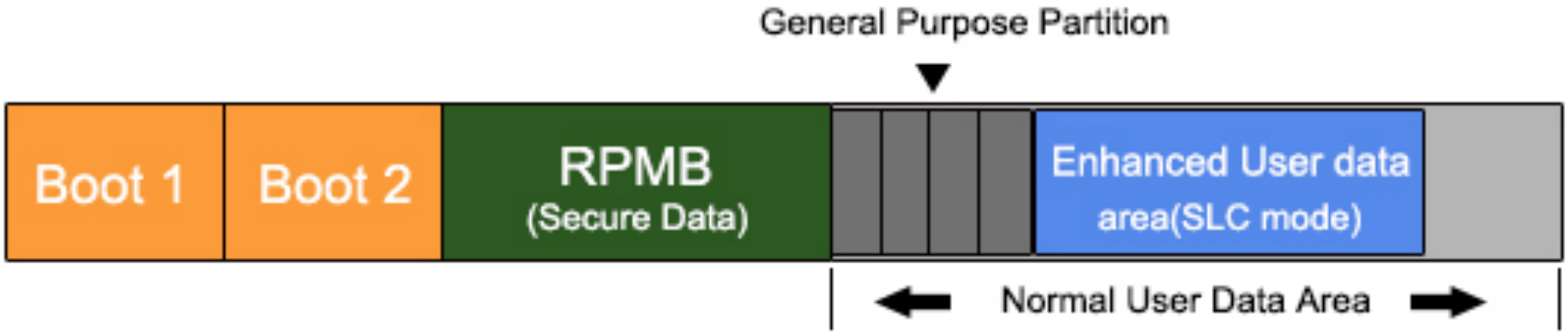
Another Challenge

- Bootloader partition is not exposed
  - Can’t read or write bootloader from Android

Bootloader on the eMMC

Bootloader is on the protected Boot 1 partition

Android can only see the blue partition



http://www.ureach-inc.com/global/Porducts-Flash-emmc.html

Writing the Bootloader

- How can we overwrite the Boot 1 partition?

Writing the Bootloader

- How can we overwrite the Boot 1 partition?

Update from Vendor requires flashing BL !!

Phone has a special “download mode” that allows flashing files to the eMMC.

One more problem!

Download mode checks file signatures when flashing.

So close...

http://www.creativityfuse.com/wp-content/uploads/2010/09/frustration.gif

How to disable the checking during flashing

The “else” branch!

We can write code to modify the signature check function in the running bootloader, and then load it through the else branch.

This lets us flash the custom bootloader to the device

Claim victory again!

Case #2.2

Samsung Galaxy Note II

- Bad News
  - The else branch was removed in firmware update
  - Added blacklisting of old bootloaders

http://instructional1.calstatela.edu/lkamhis/tesl565_sp11/gimbrone_zabayle/bouncers.jpg

We need a new mechanism for putting the custom bootloader on the eMMC Boot partition

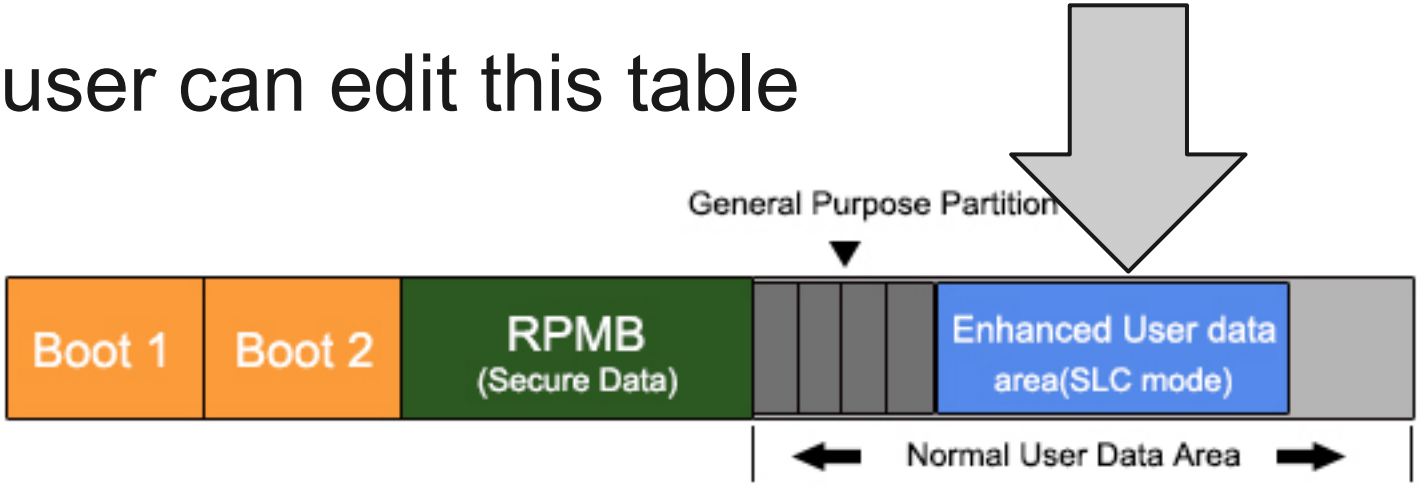
Let’s investigate the firmware update mechanism

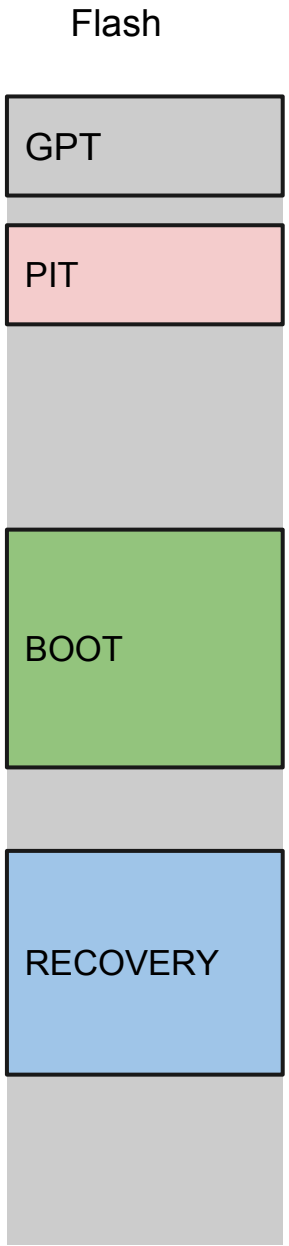
Flash Signature Checking

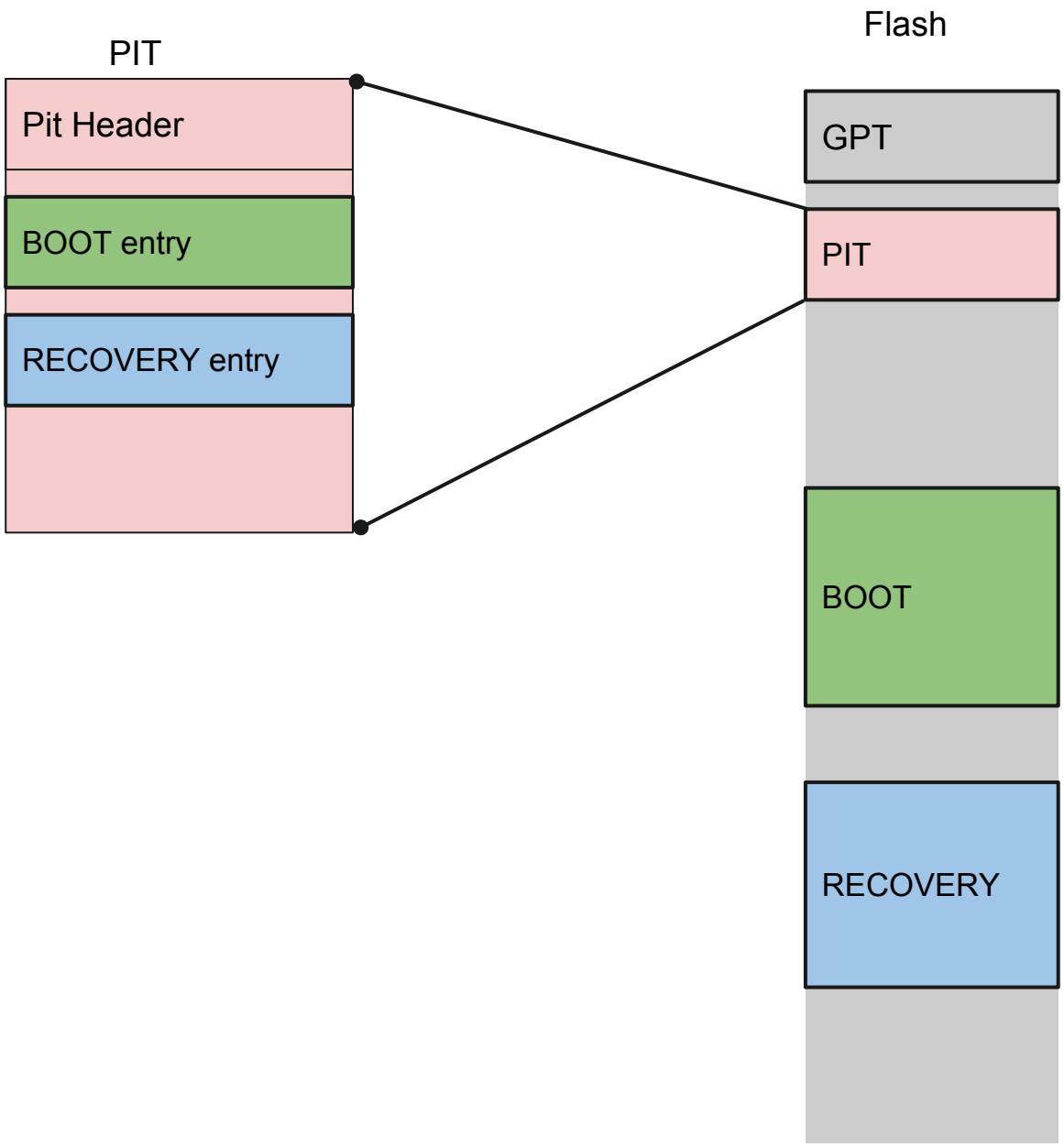
- What kind of checks are performed?
  - RSA-2048
- Under what condition is the check performed?
  - Partitions with certain names, such as “BOOT”
- Where does it get the partition information?

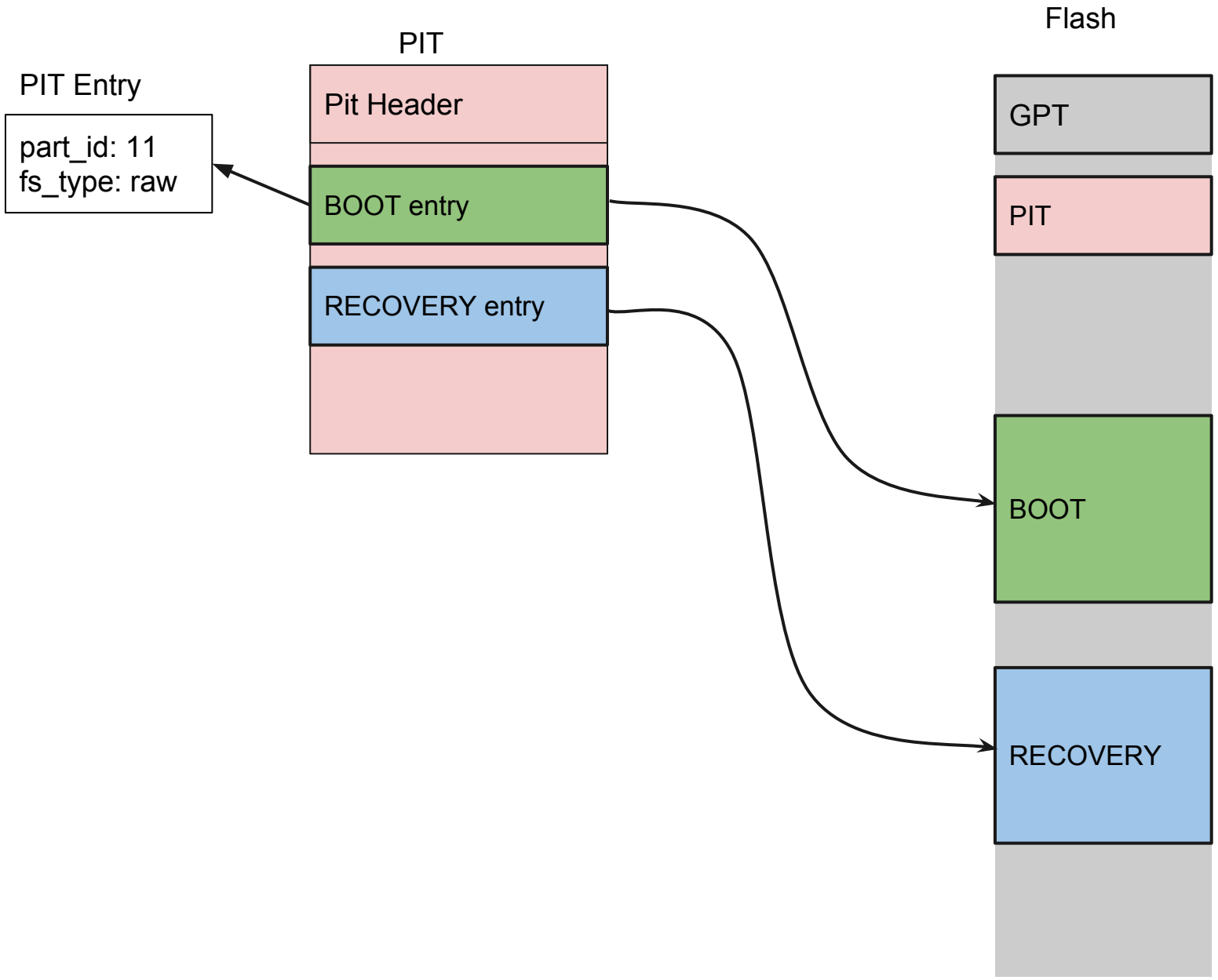
Partition Information Table

- Secondary partition table
- Additional partition metadata
  - id, filesystem
- Root user can edit this table




Flash
GPT
PIT
BOOT
RECOVERY

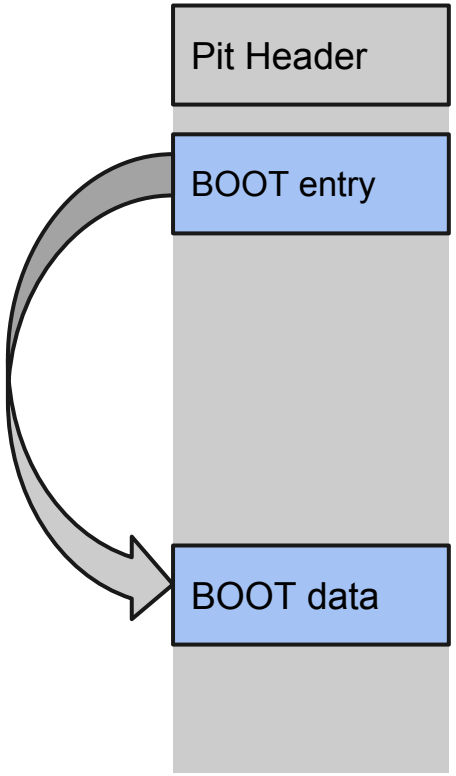

PIT
Pit Header
BOOT entry
RECOVERY entry
Flash
GPT
PIT
BOOT
RECOVERY


PIT Entry
part_id: 11
fs_type: raw
PIT
Pit Header
BOOT entry
RECOVERY entry
Flash
GPT
PIT
BOOT
RECOVERY

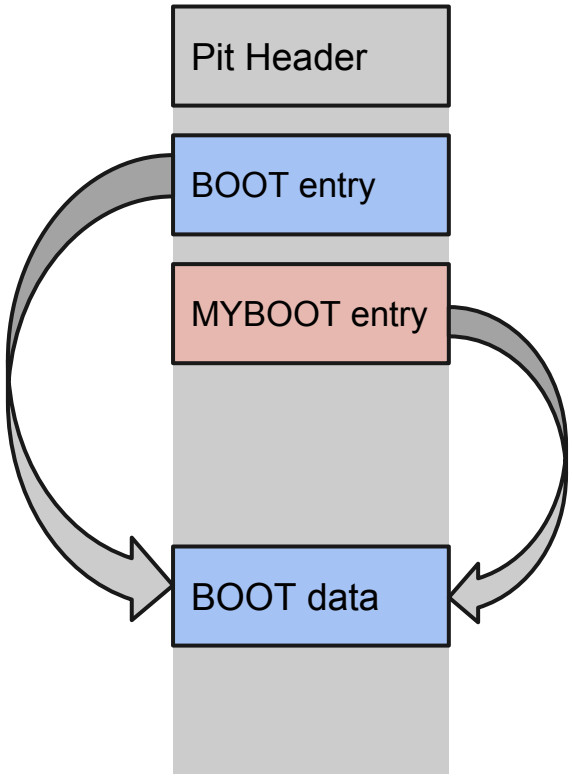
Bypassing the Flash Check

- Create a duplicate PIT entry for the bootloader partition
- Change the partition name to avoid checking
- The entries would point to the same location on the eMMC

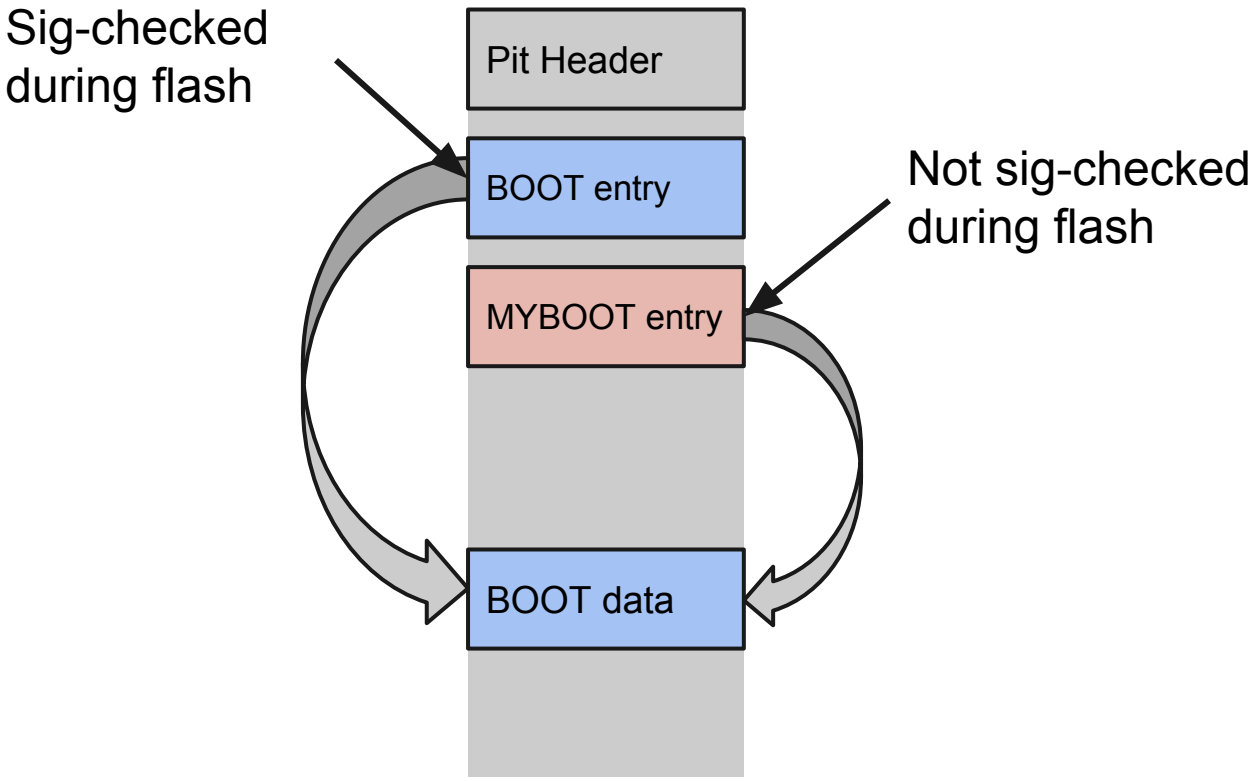
Original PIT



Custom PIT



Custom PIT


Sig-checked
during flash
Pit Header
BOOT entry
Not sig-checked
during flash
MYBOOT entry
BOOT data

Success

- This was effective in bypassing the signature check.
- The custom bootloader from Case 2.1 was now flashable

Case #2.3

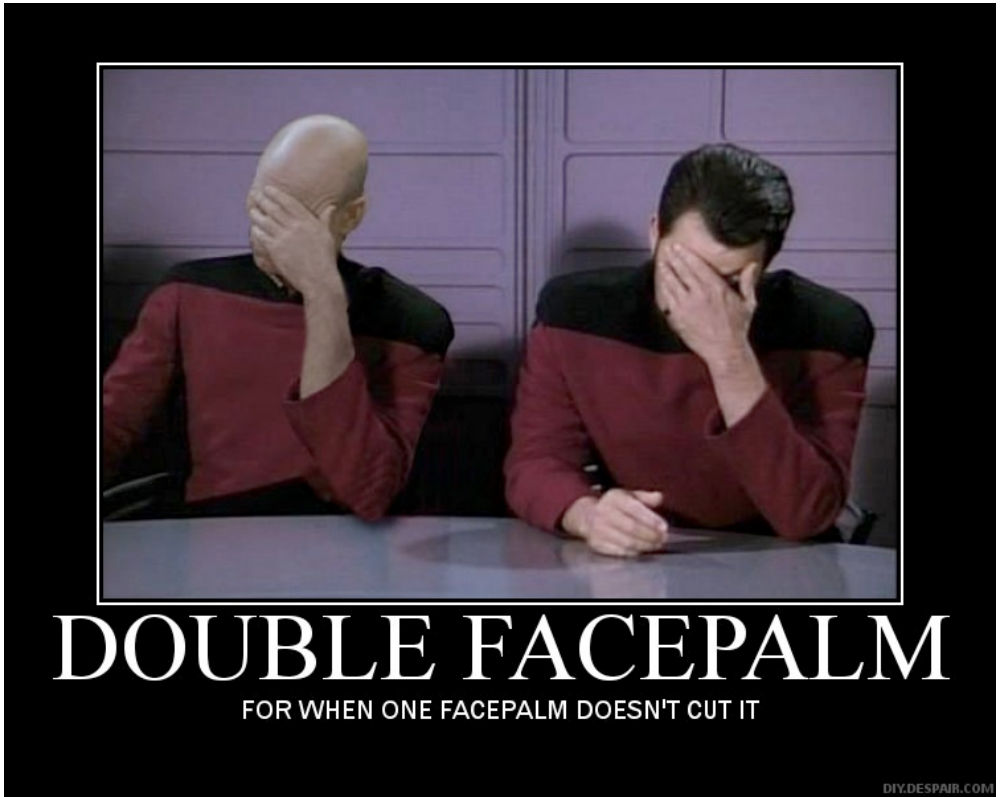
Note II Lightning Round

Samsung added a signature check on the PIT area at boot time in a new bootloader revision.

- The PIT area could no longer be altered to add custom entries.

But… downgrade works

➔ ...the developers forgot to blacklist the previous bootloader file.



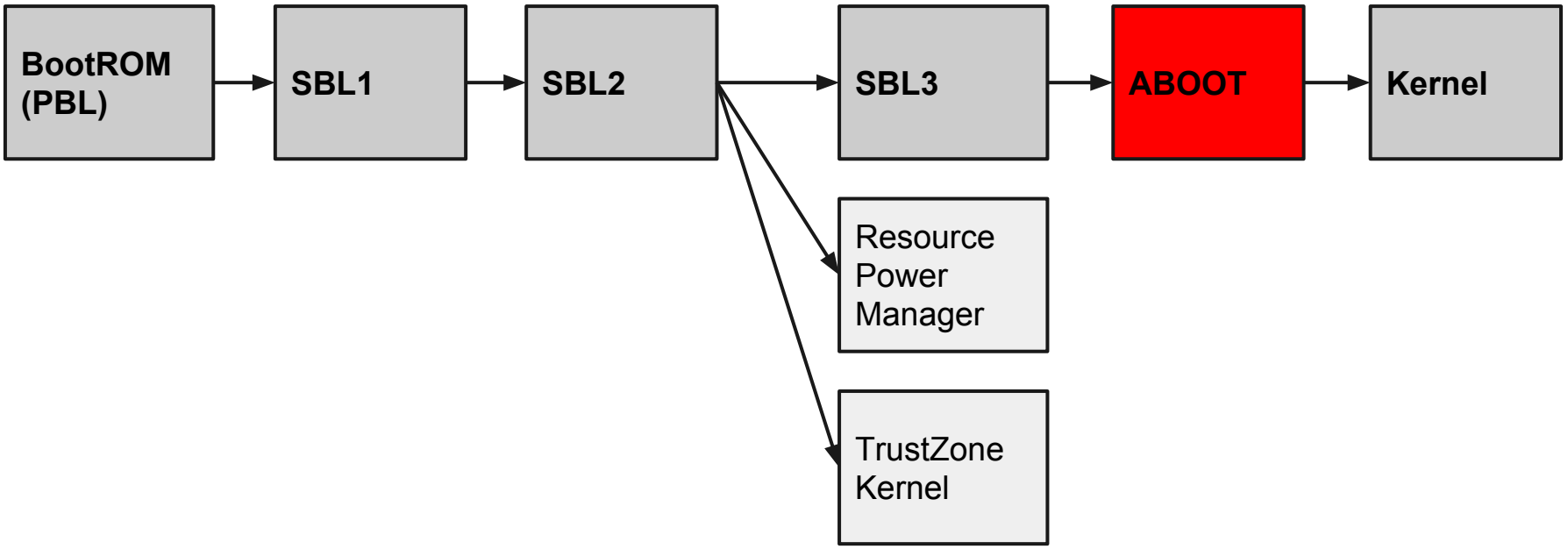
Case #3

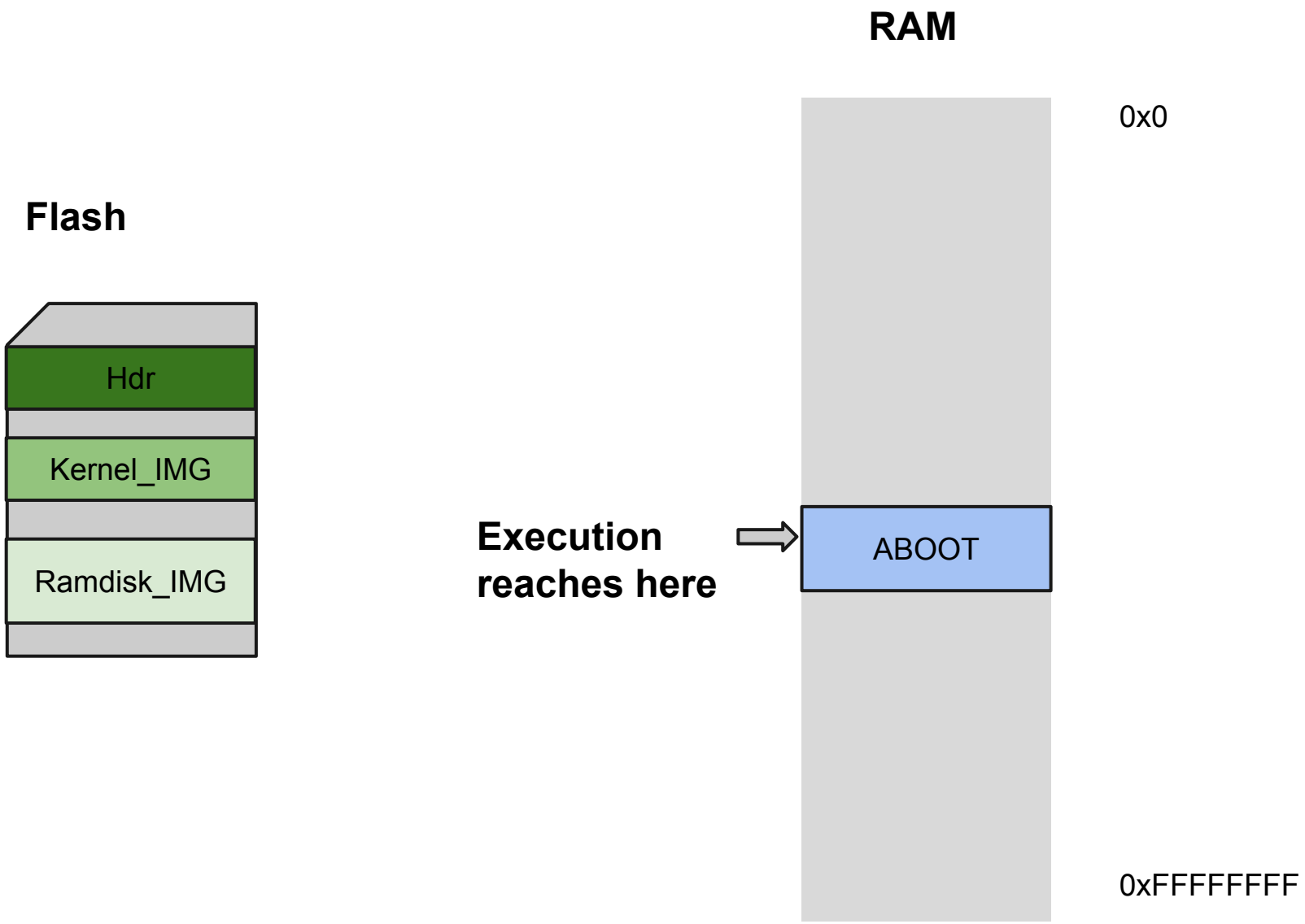
Samsung Galaxy S4

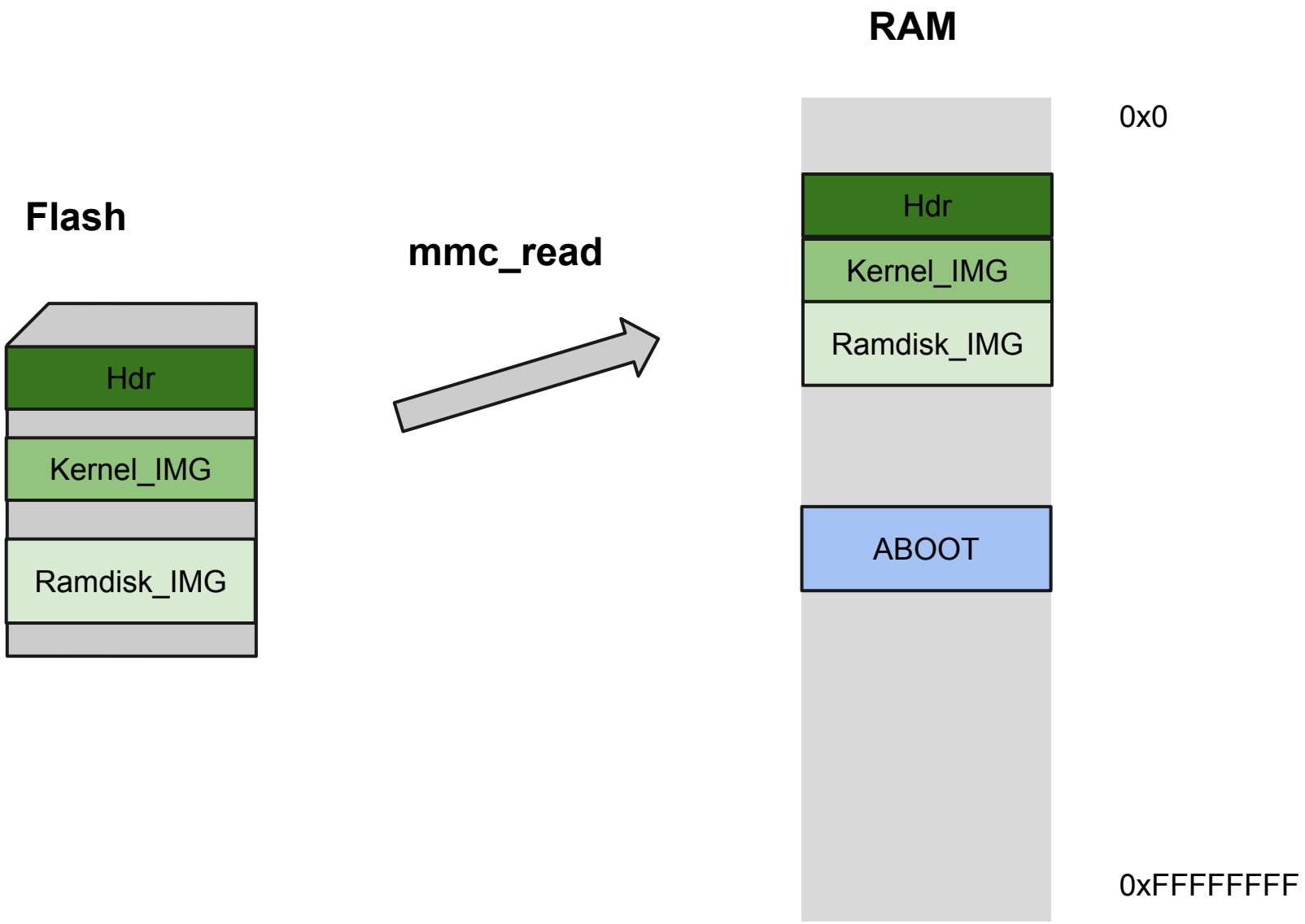
- Released in April 2013
- Based on the Qualcomm Snapdragon 600
- Some service providers also requested to lock down their version of devices.

Goal: Boot a custom kernel

S4 Boot Flow


BootROM (PBL)
SBL1
SBL2
SBL3
ABOOT
Kernel
Resource Power Manager
TrustZone Kernel

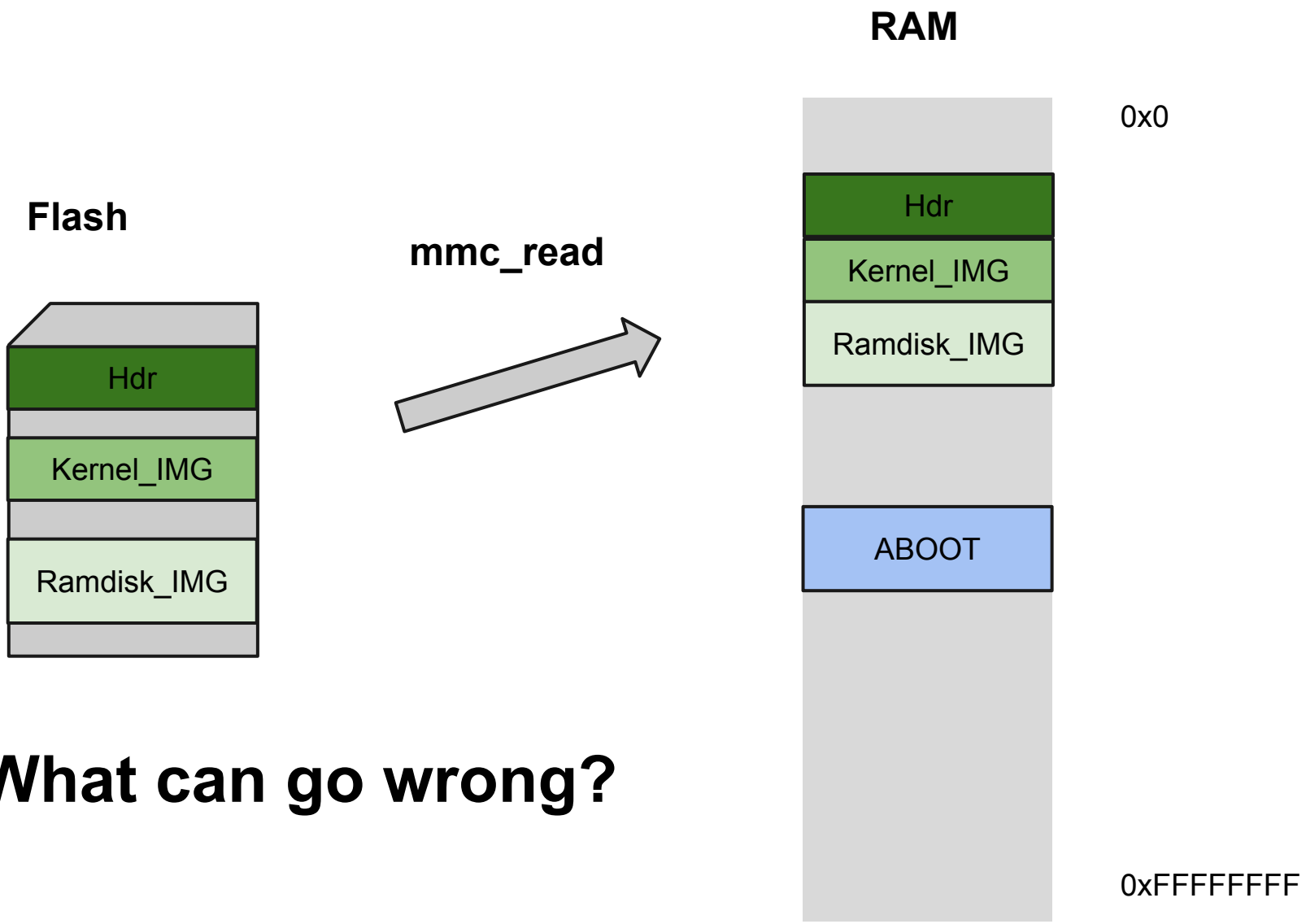

RAM
0x0
Flash
Hdr
Kernel_IMG
Ramdisk_IMG
Execution reaches here
ABOOT
0xFFFFFFFF


RAM
0x0
Flash
mmc_read
Hdr
Kernel_IMG
Ramdisk_IMG
Hdr
Kernel_IMG
Ramdisk_IMG
ABOOT
0xFFFFFFFF

How Sections Load Into Memory

// mmc_read(disk_src, mem_dst, size)

mmc_read(**ptn_start**, **&hdr**, **PAGE_SIZE**);
mmc_read(**kernel_start**, **hdr.kernel_addr**, **hdr.ksize**);
mmc_read(**ramdisk_start**, **hdr.rd_addr**, **hdr.rdsize**);



What can go wrong?

Who controls hdr?

```
// Load sections into memory
mmc_read( ptn_start,        &hdr, PAGE_SIZE );
mmc_read( kernel_start,     hdr.kernel_addr, hdr.ksize );
mmc_read( ramdisk_start,    hdr.rd_addr, hdr.rdsize );
```

Who controls hdr?

```
// Load sections into memory
mmc_read( ptn_start,      &hdr, PAGE_SIZE );
mmc_read( kernel_start,   hdr.kernel_addr, hdr.ksize );
mmc_read( ramdisk_start,  hdr.rd_addr, hdr.rdsize );
```

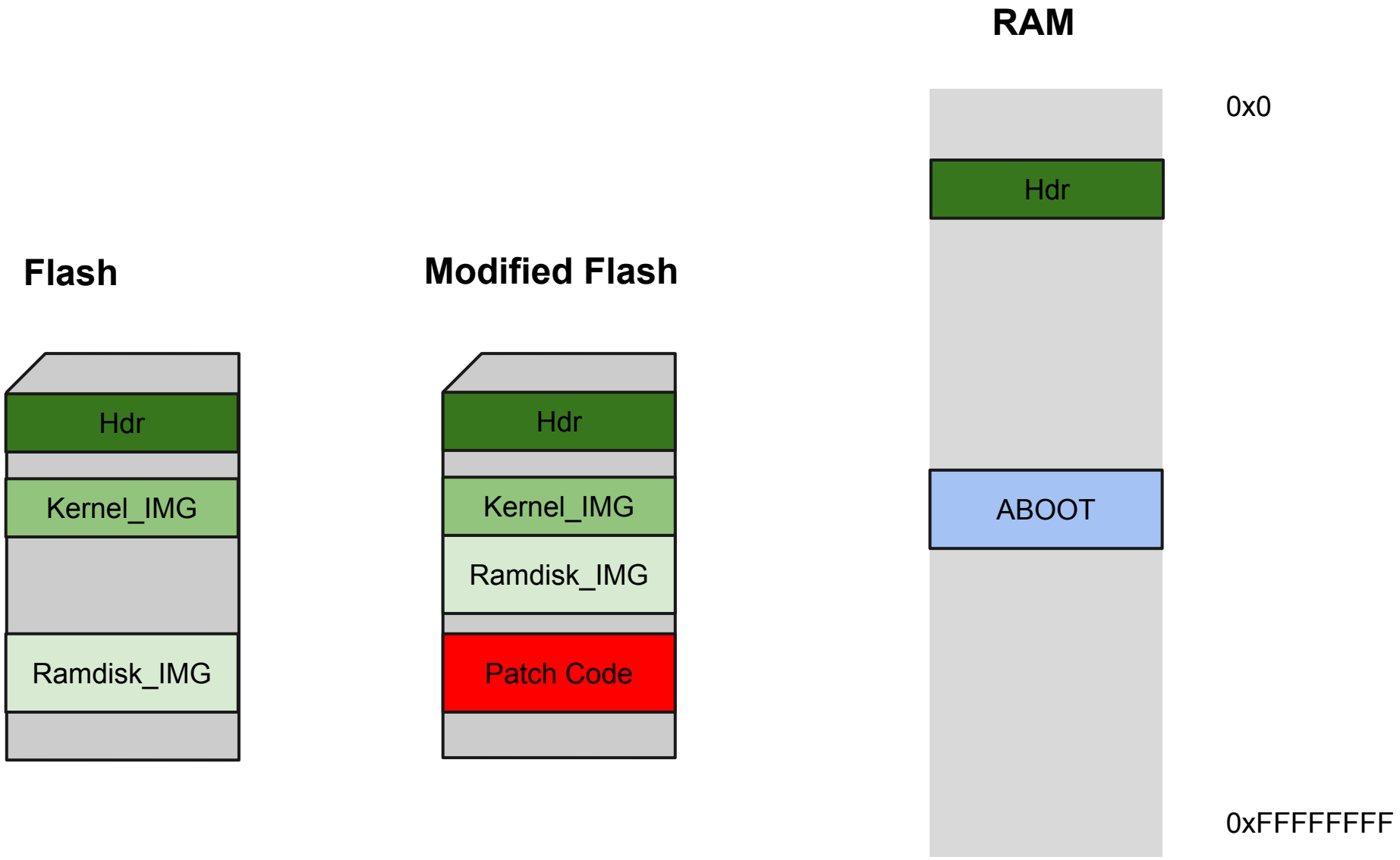
Spot the problem?

- No input validation
- Able to load code anywhere
- **Even on top of the bootloader**

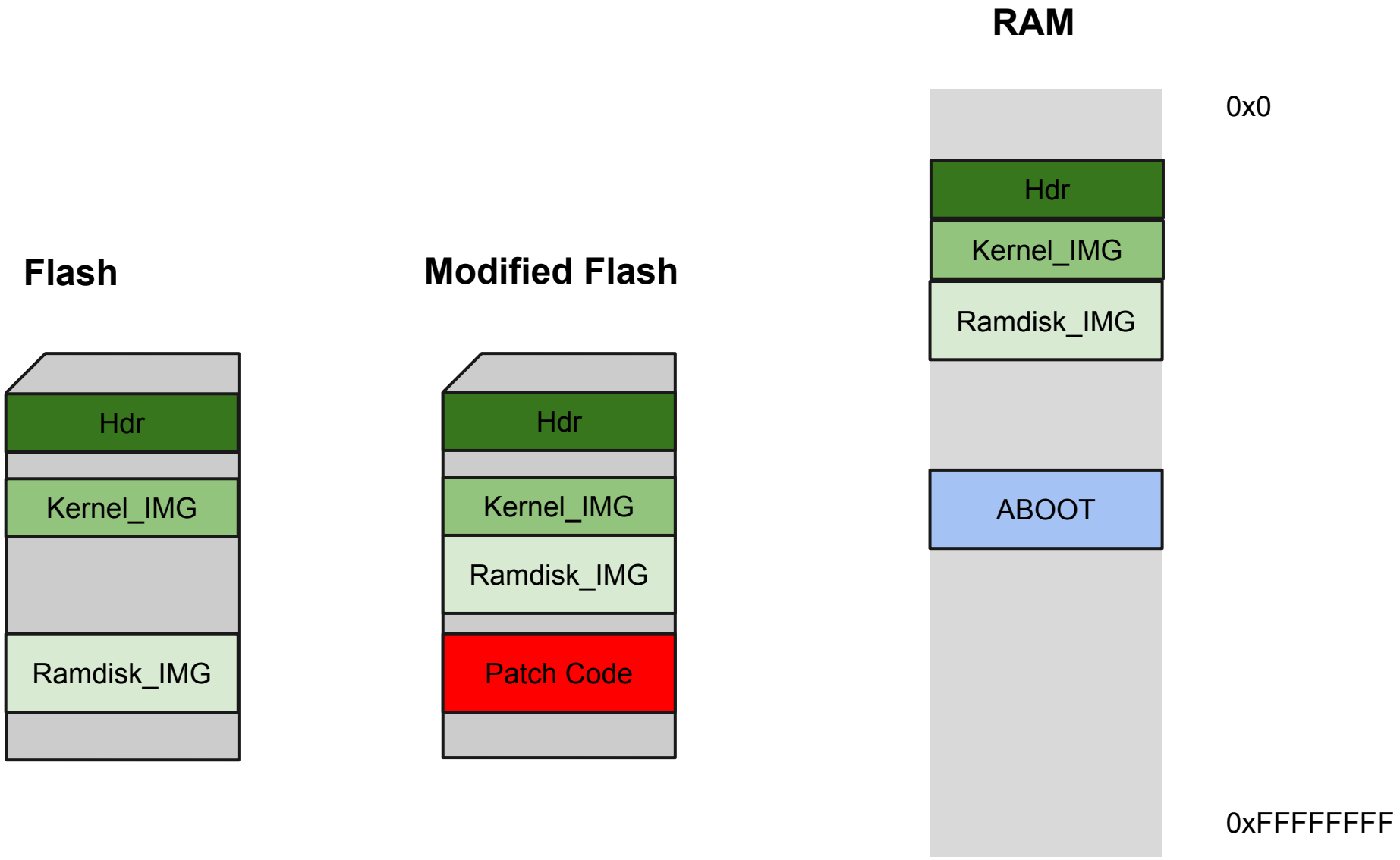
Exploit

- Second mmc_read loads a combined kernel + ramdisk
- Third mmc_read overwrites the signature checking function
- First published by Dan Rosenberg
- Affected many other vendors (e.g. LG)

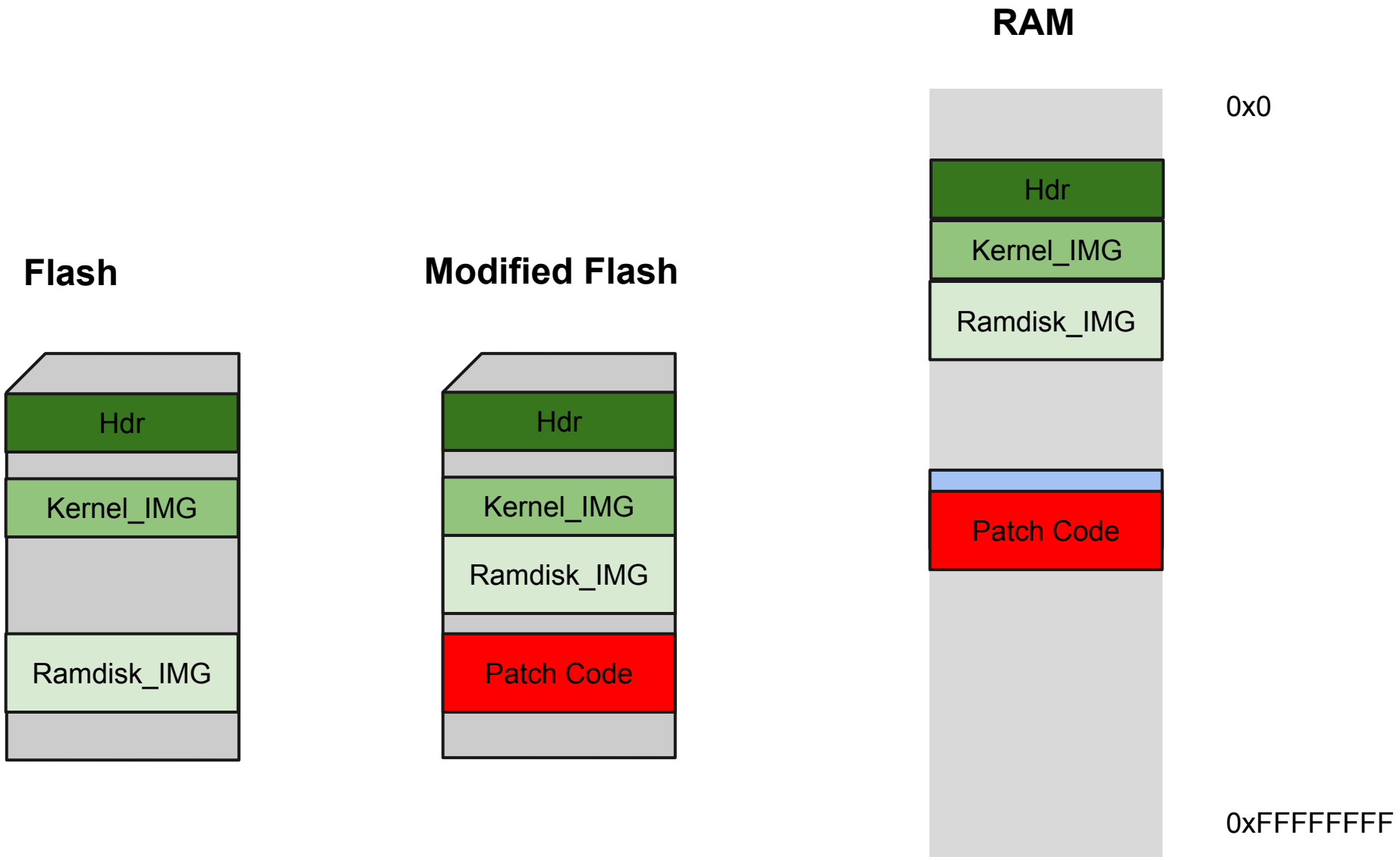
First mmc_read



Second mmc_read



Third mmc_read



Summary

- Six bootloader software errors
  - Case sensitive vs insensitive search
  - Additional debugging (else) branch
  - Failed to revocation signed modules
  - Forgot to blacklist old bootloader
  - Missing integrity check to PIT table
  - Failed to validate the image header

- Most of them are NOT conventional memory vulnerabilities.

Summary

- Problems are not limited to a single vendor.
  - Samsung is very responsive to troubleshoot.
  - All bugs shown are patched in Samsung devices.
  - Some bugs are common across vendors.
- Vendors are often open to allow loading customized kernels.
- The “distrust” comes from service providers.

Thanks!

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