KU LEUVEN

An in-depth security evaluation of the Nintendo DSi gaming console

CARDIS 2023

pcy Sluys, Lennert Wouters, Benedikt Gierlichs, Ingrid Verbauwhede

COSIC-KU Leuven

2023-11-15

Outline

Outline

What

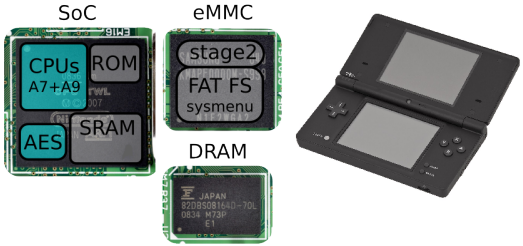
- Nintendo DSi — Released in 2008
- Dualcore ARM7 (I/O) + ARM9 (GPU)
- Security and boot process not yet fully analyzed

Why

- Jailbreaks already exist
- But rely on eMMC (nonvolatile memory) integrity!
  - Short erase-write cycle lifetime
  - Buggy wear-levelling firmware?[1]
- $\Rightarrow$ bypass ROM to revive bricked consoles

[1] cf. https://media.ccc.de/v/34c3-8784-emmc_hacking_or_how_i_fixed_long-dead_galaxy_s3_phones

Boot process



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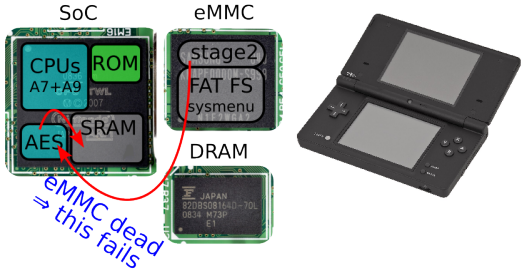
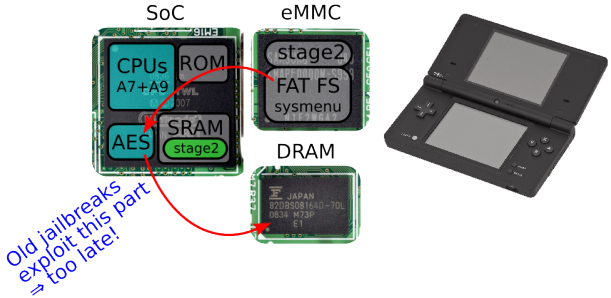
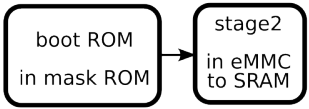


boot ROM
in mask ROM

Boot process





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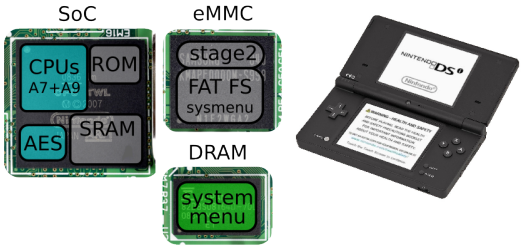

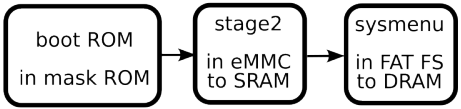

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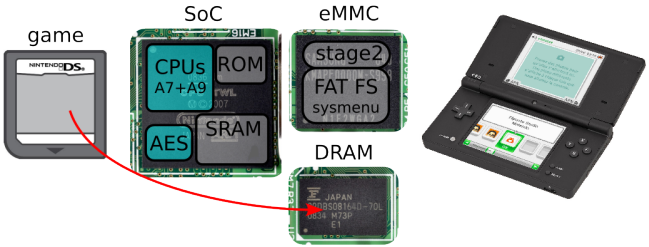

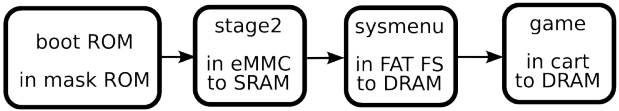

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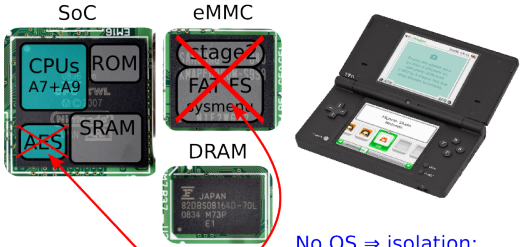
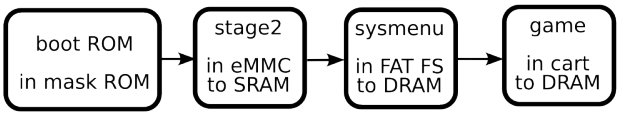
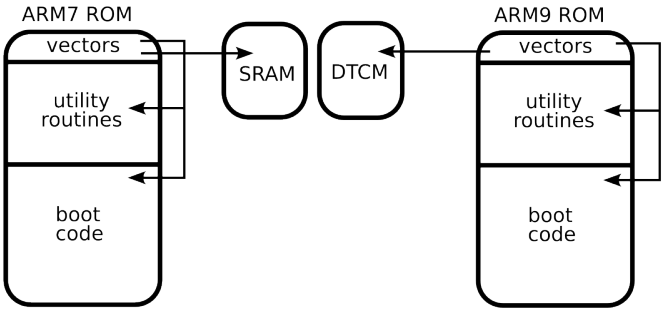




Outline

Situation


ARM7 ROM
vectors
utility routines
boot code
SRAM
DTCM
ARM9 ROM
vectors
utility routines
boot code

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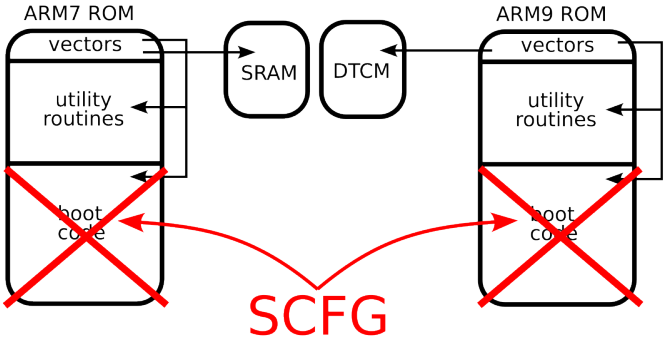
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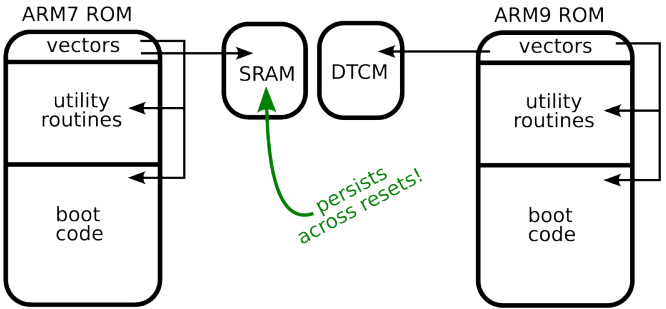
SCFG

Extraction strategy



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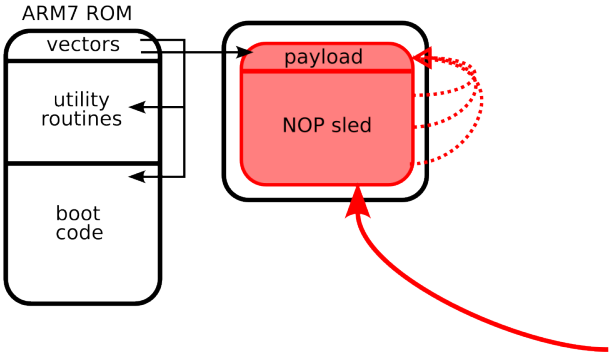

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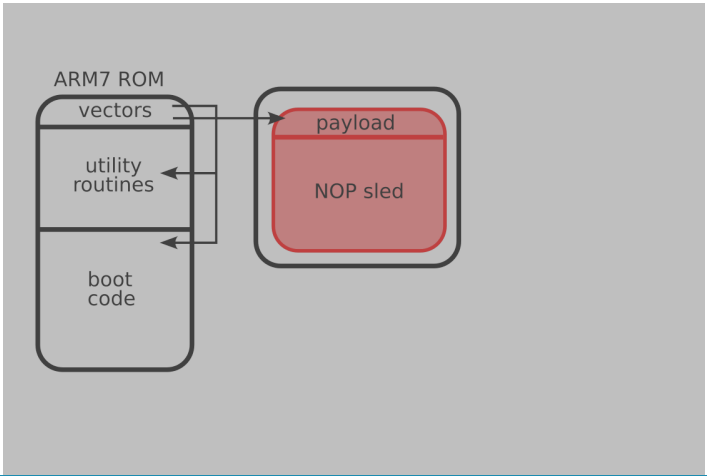

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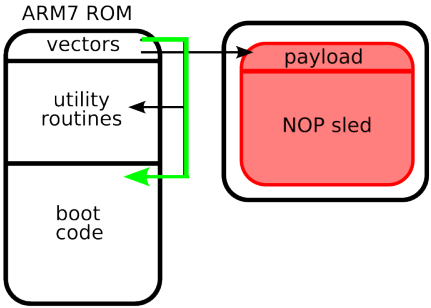

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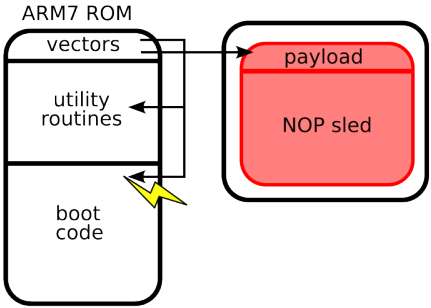

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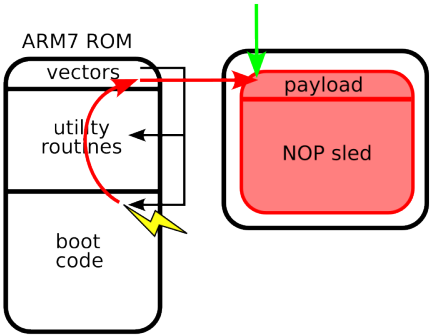


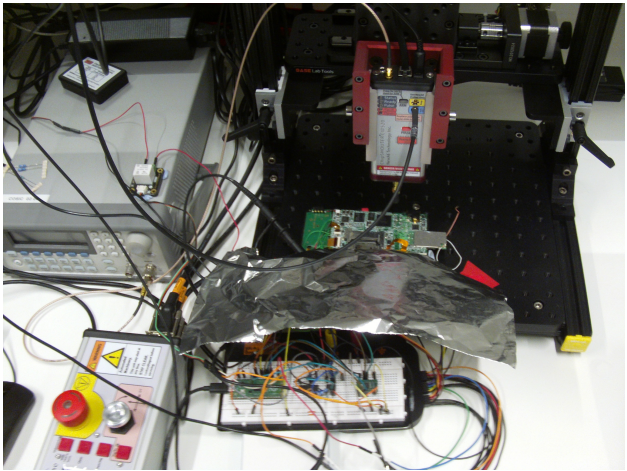
Extraction strategy

✓ ARM7 code execution

Extraction strategy

- ✓ ARM7 code execution
- ✓ While boot ROM is running

Setup



Result

SHA3-256(ARM7 ROM):

`ccc5cce4ece3204e6ece25bdf5684004 3375ce1771fb998ed9f641ca9fe00bc1`

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`ccc5cce4ece3204e6ece25bdf5684004 3375ce1771fb998ed9f641ca9fe00bc1`

But...

Result

SHA3-256(ARM7 ROM):
`ccc5cce4ece3204e6ece25bdf5684004 3375ce1771fb998ed9f641ca9fe00bc1`

But...

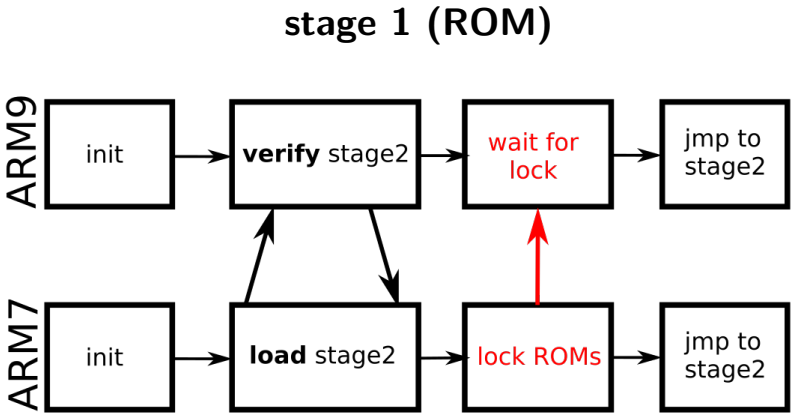
Only I/O driver code!

⇓

ARM9 implements cryptography

Outline

Extraction strategy



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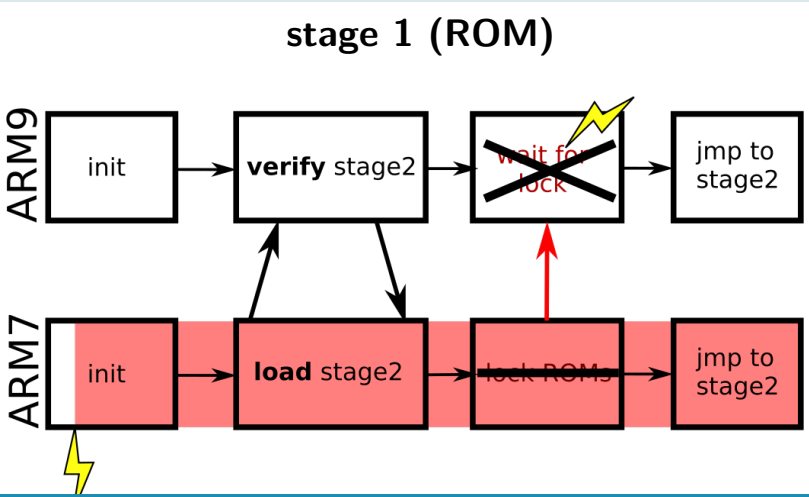

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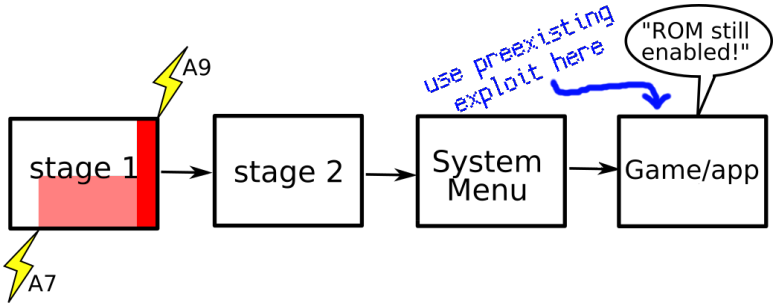


Extraction strategy

One success every 90 minutes

Result

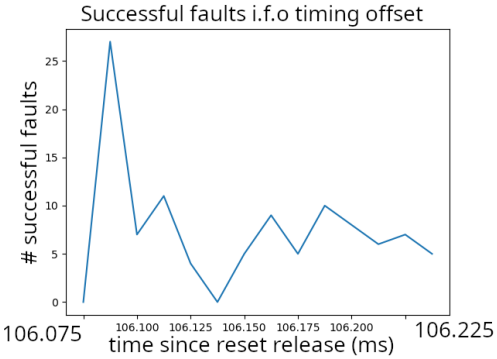
SHA3-256(ARM9 ROM):

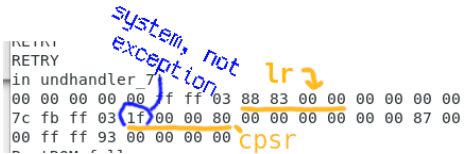
cb886a6a02164ee8d4e1409d6e4c9bec 9736958e6e879f3ea7e44561ab667c6f

```
int NANDboot_verify_st2bin(void)

{
  BootFlags BVar1;
  int r;
  uint status;
  uint comprtype;
  int rv;

  status = (uint)(g_nandboot_hdrptr->hdr).flags;
  rv = 0;
  if ((-1 < (int)(status << 0x1c)) || (-1 < (int)(status << 0x1e))) {
    pxi_wait_state3_arg(6);
  }
  mbk_map_bin7_to_arm9(&(g_nandboot_hdrptr->hdr).meminfo);
  status = (uint)(g_nandboot_hdrptr->hdr).flags;
  comprtype = 0;
  if (((int)(status << 0x1c) < 0) && ((int)(status << 0x1e) < 0)) {
    comprtype = 2;
  }
  NANDboot_decompr_if_needed(&(g_nandboot_hdrptr->hdr).arm7info,&g_nandboot_filecb,comprtype);
  r = NANDboot_verify_st2a7(&g_gcdboot_rsamsg,g_nandboot_hdrptr);
  if (r == 0) {
    rv = -3;
  }
  cp15_dcache_flush_invalidate();
  BVar1 = (g_nandboot_hdrptr->hdr).flags;
```

Outline

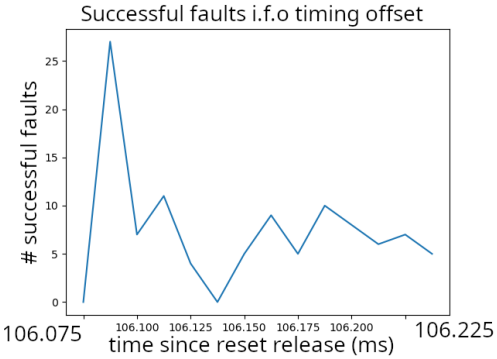
FI parameters

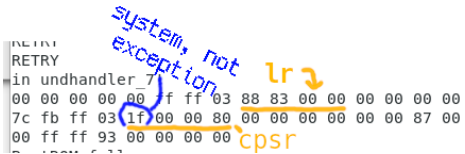





```
_start:
    cpsid i      // interrupt disable
    ldr sp, =0x...
    bl  powerup_stuff
    bl  clear_entire_sram
    b   main
```

FI parameters



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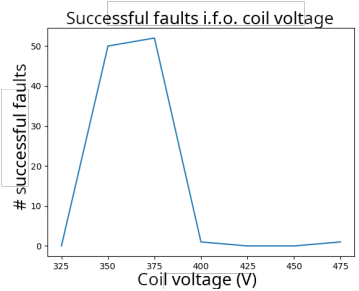
⇒ **Direct `pc` corruption, no interrupt/exception**

FI parameters



Electromagnetic fault injection: towards a fault model on a 32-bit microcontroller

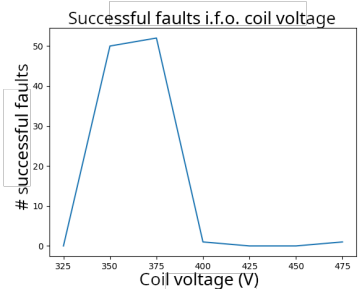
Nicolas Moro*‡, Amine Dehbaoui†, Karine Heydemann‡, Bruno Robisson*, Emmanuelle Encrenaz‡
*Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA)

Table III: Influence of the pulse's voltage

Pulse voltage	Loaded value	Occurrence rate
170 V	1234 5678 (no fault)	100%
172 V	1234 5678 (no fault)	100%
174 V	9234 5678	73%
176 V	FE34 5678	30%
178 V	FFF4 5678	53%
180 V	FFFD 5678	50%
182 V	FFFF 7F78	46%
184 V	FFFF FFFB	40%
186 V	FFFF FFFF	100%
188 V	FFFF FFFF	100%
190 V	FFFF FFFF	100%

(table from above paper)

FI parameters



01 00 a1 b8	stmialt r1!, {r0}
01 00 af b8	stmialt pc!, {r0}
ff 3f 9d b8	ldmialt sp, {r0-r12,sp}

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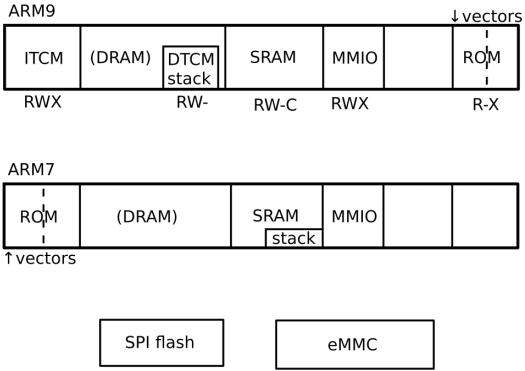
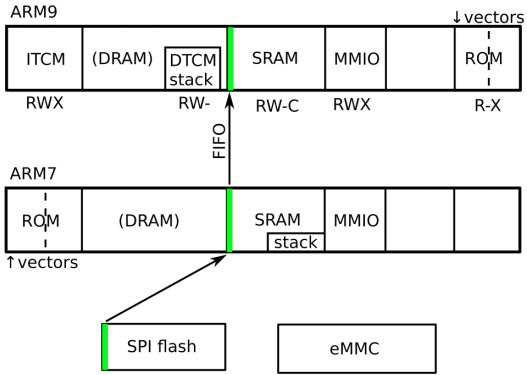
Boot procedure

Memory maps:



Boot procedure

1. Load boot configuration



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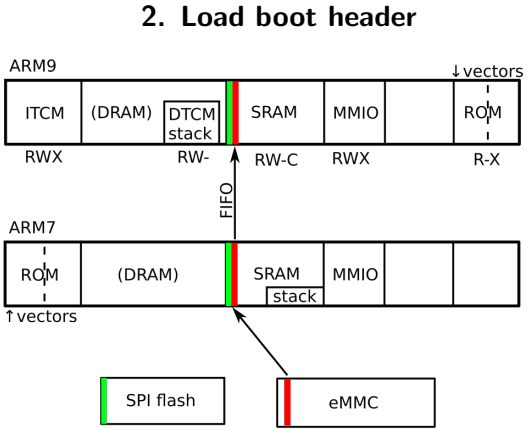

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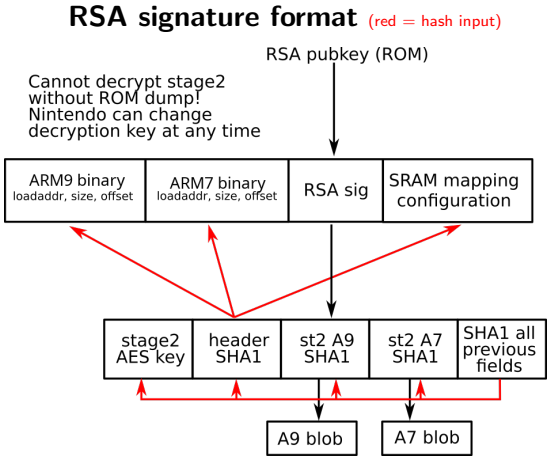

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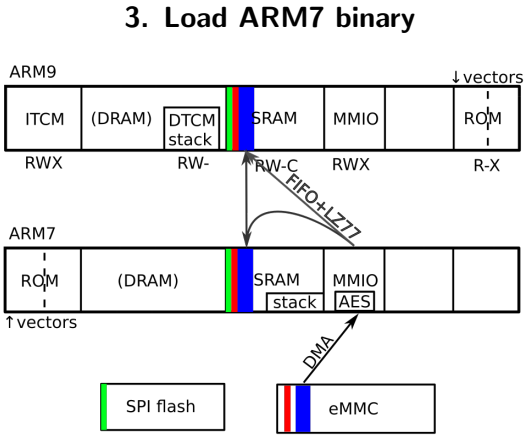

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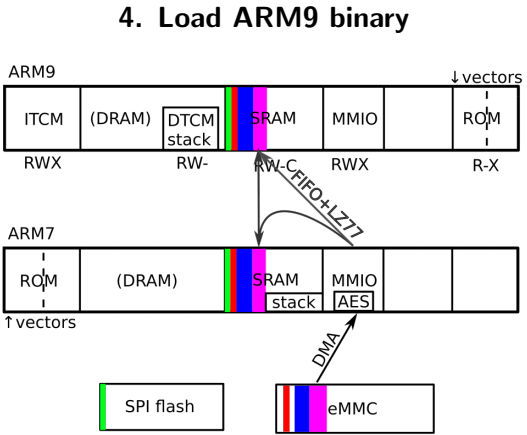
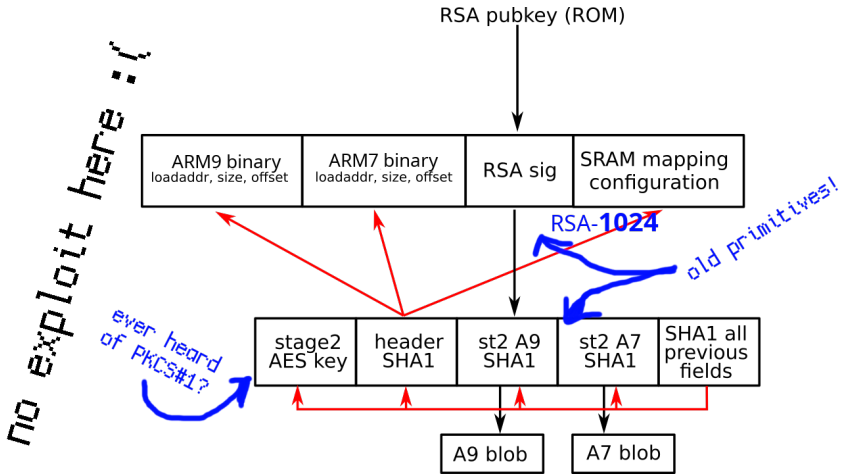


Outline

Cryptography



Vulnerabilities?

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- No complex protocol $\Rightarrow$ no protocol bugs ($\Leftrightarrow$ Switch)

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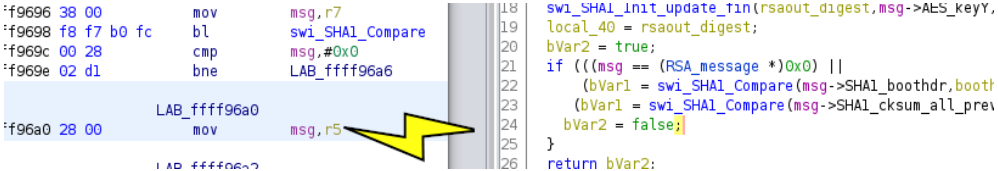
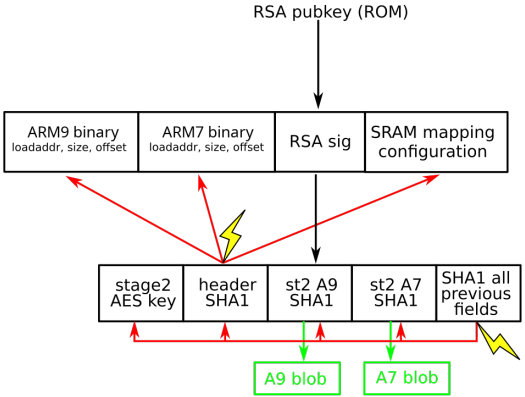
- No complex protocol $\Rightarrow$ no protocol bugs ($\Leftrightarrow$ Switch)
- Different attack strategy needed

Vulnerabilities



Exploit overview



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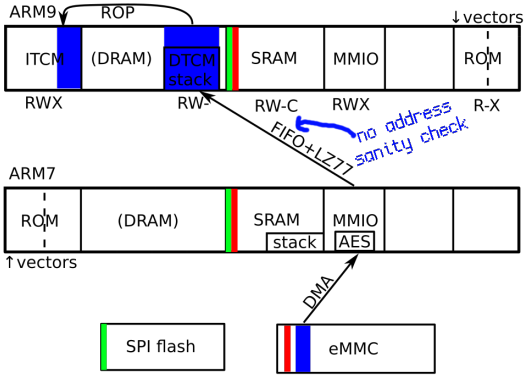

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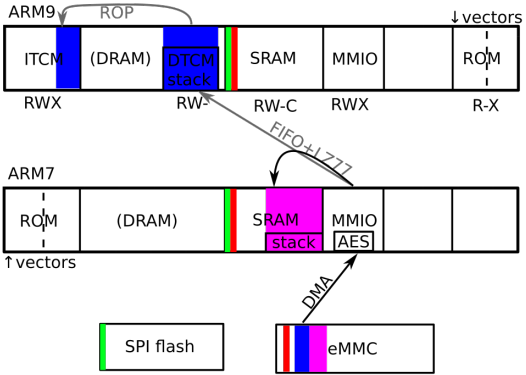


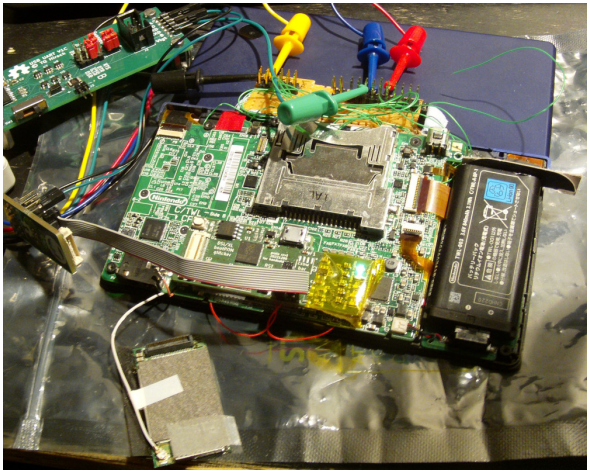
Exploit overview

✓ ARM7 *and* ARM9 code execution

Exploit overview

- ✓ ARM7 *and* ARM9 code execution
- ✓ Only one glitch

In action



Outline

Conclusion

- **DSi secure boot broken**
  - ... long after its active lifetime
  - ... with a rather complex physical attack
- **'Flimsy' security system still worked?**
  - No OS, no TEE, old crypto!

Conclusion

What do these have in common?

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Conclusion

- **Keep bootroms simple**
- **Second-order fault injection attacks are not purely theoretical**
- **Breaking DRM is needed for preservation**
  - Are we the baddies?

The end

Slides: https://pcy.be/tmp/priv/cardis-dsi.pdf