SILM Security of software / hardware interfaces

Summer school, 8-12/07/2019, Inria Rennes

Session #2: Fault Injection Attacks

Niek Timmers (independent)

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What are typical targets?

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  - Incl. basic MCUs and (very) advanced SoCs
- Most standard architectures are affected
  - i.e. ARM, MIPS, Intel, etc.
- Fast processing (> 1GHz) is not a show stopper

Fault Injection Goals

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  - e.g. debug interface protection, secure boot, etc.
- Hijacking control flow
  - i.e. achieving arbitrary code execution
- Breaking cryptographic algorithms
  - i.e. differential fault analysis (DFA) attacks

Let’s attack something…

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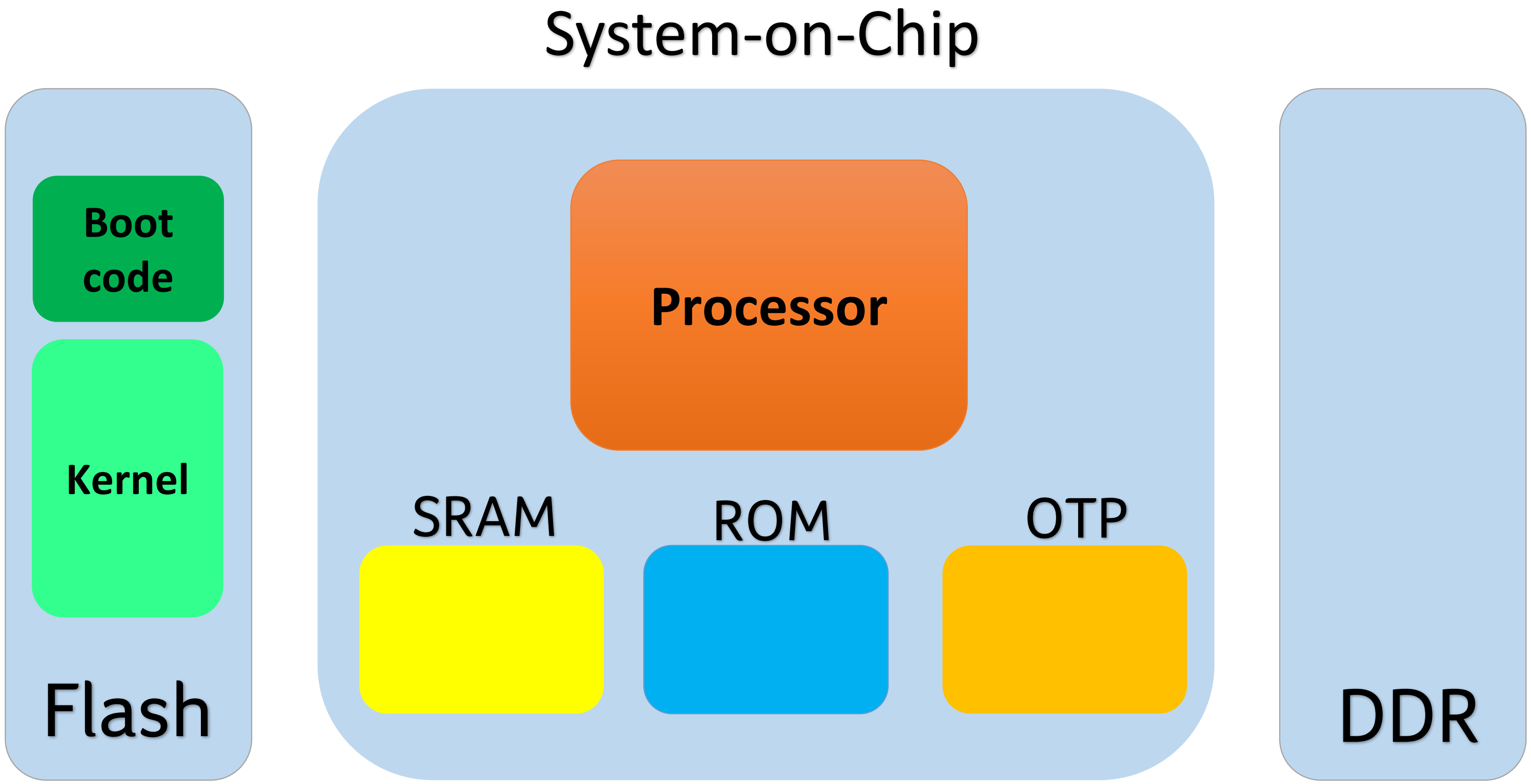
Let’s attack Secure Boot!

Why do we need secure boot?



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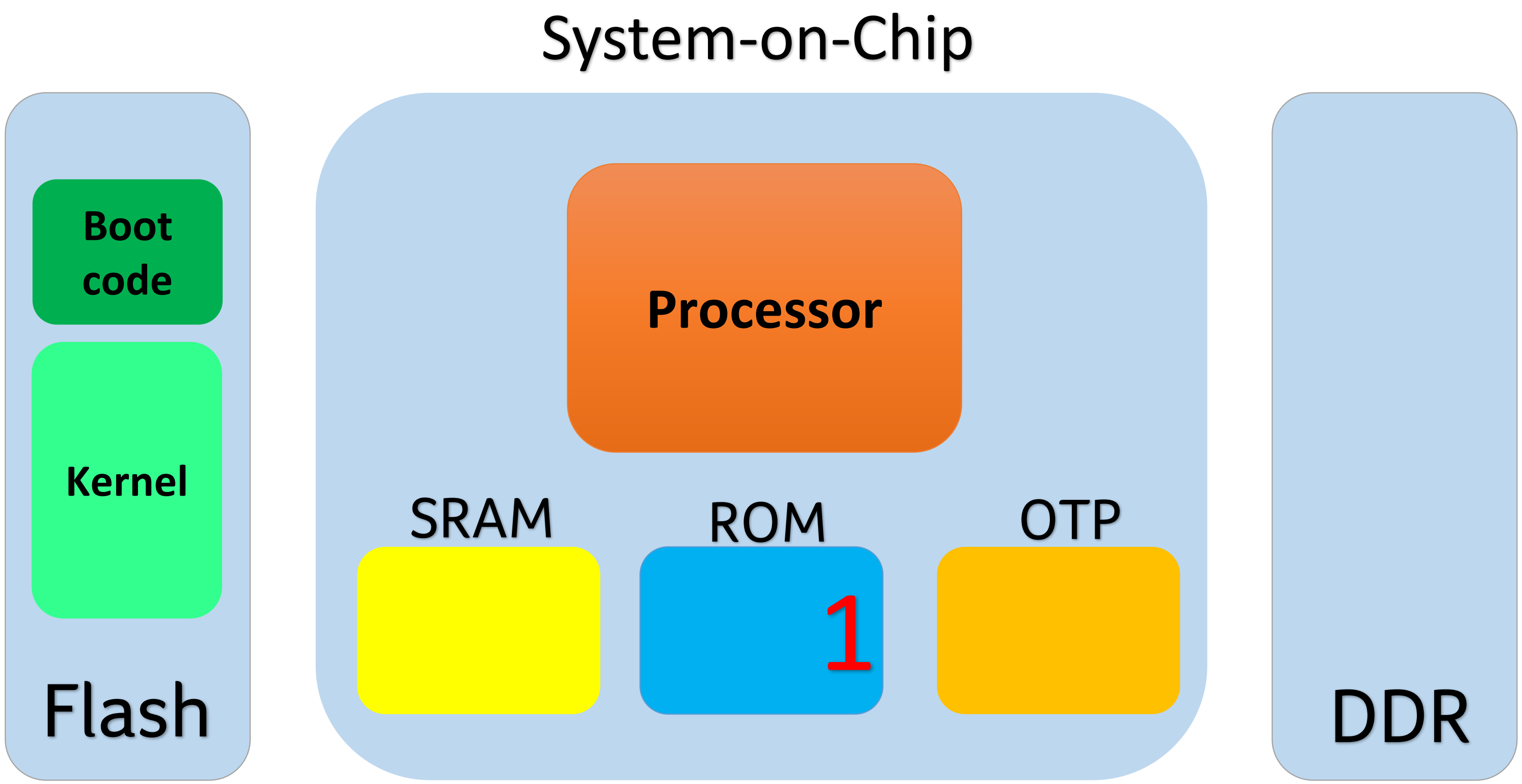

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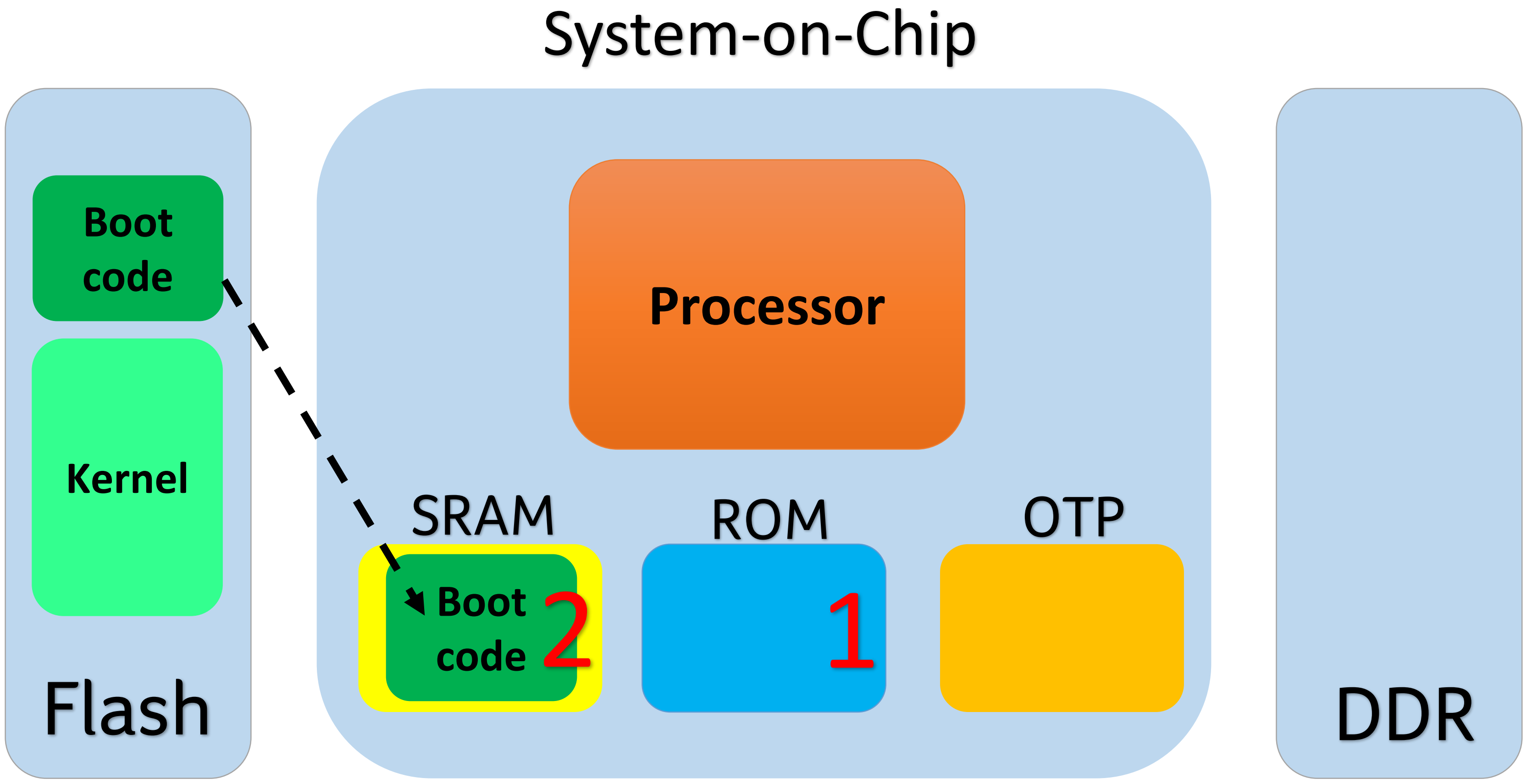

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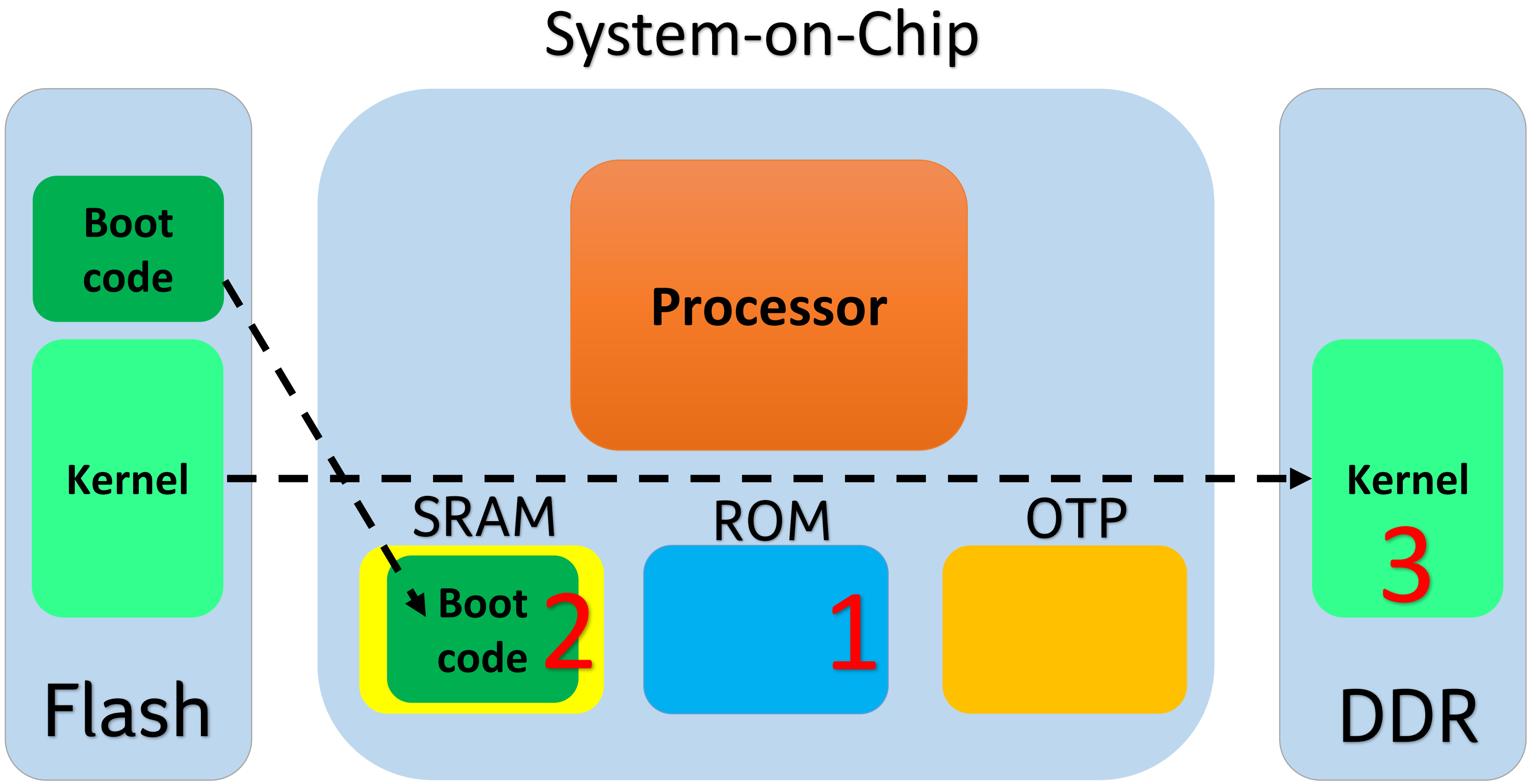

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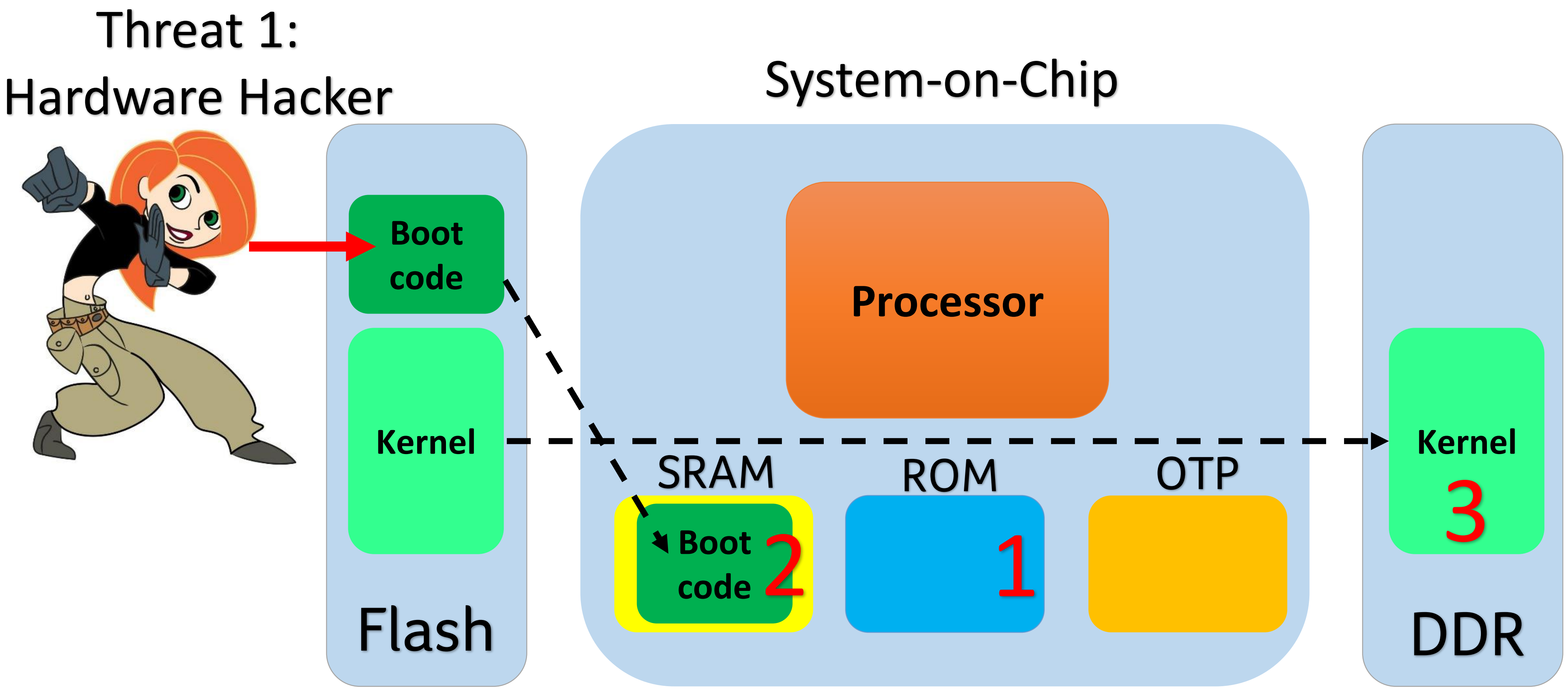

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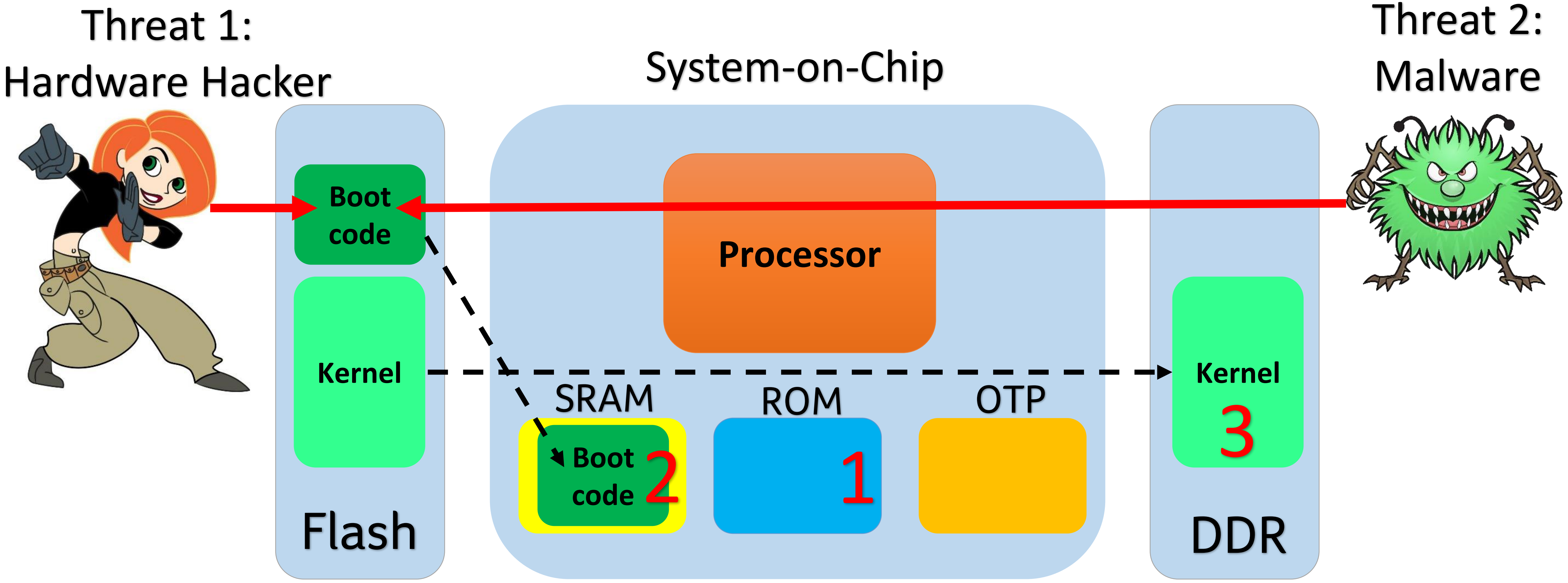

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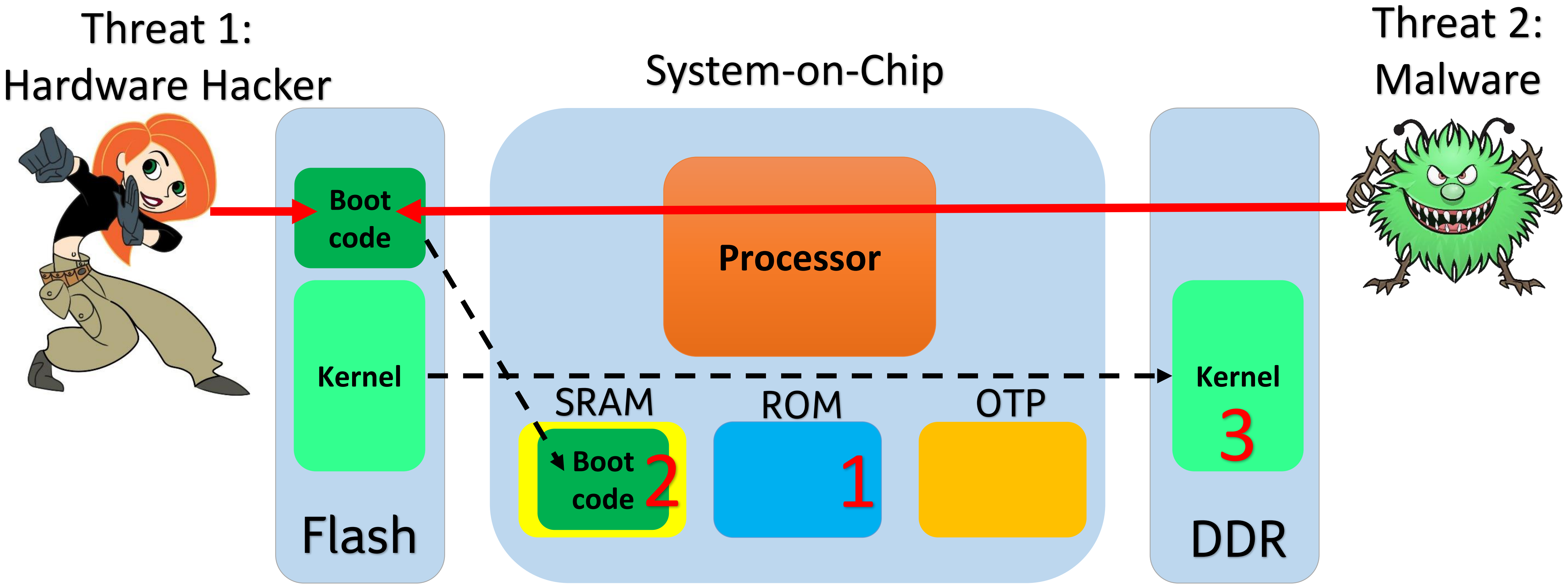

Secure boot assures integrity of code/data in flash!

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- (optional): assure confidentiality by encrypting flash

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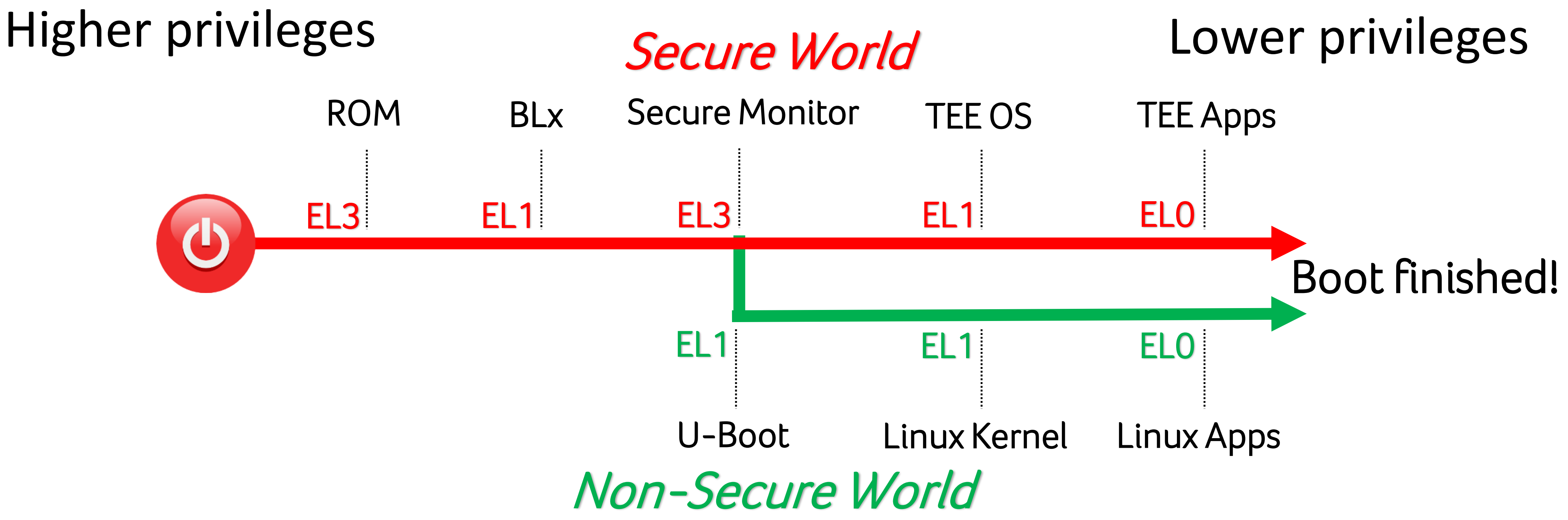

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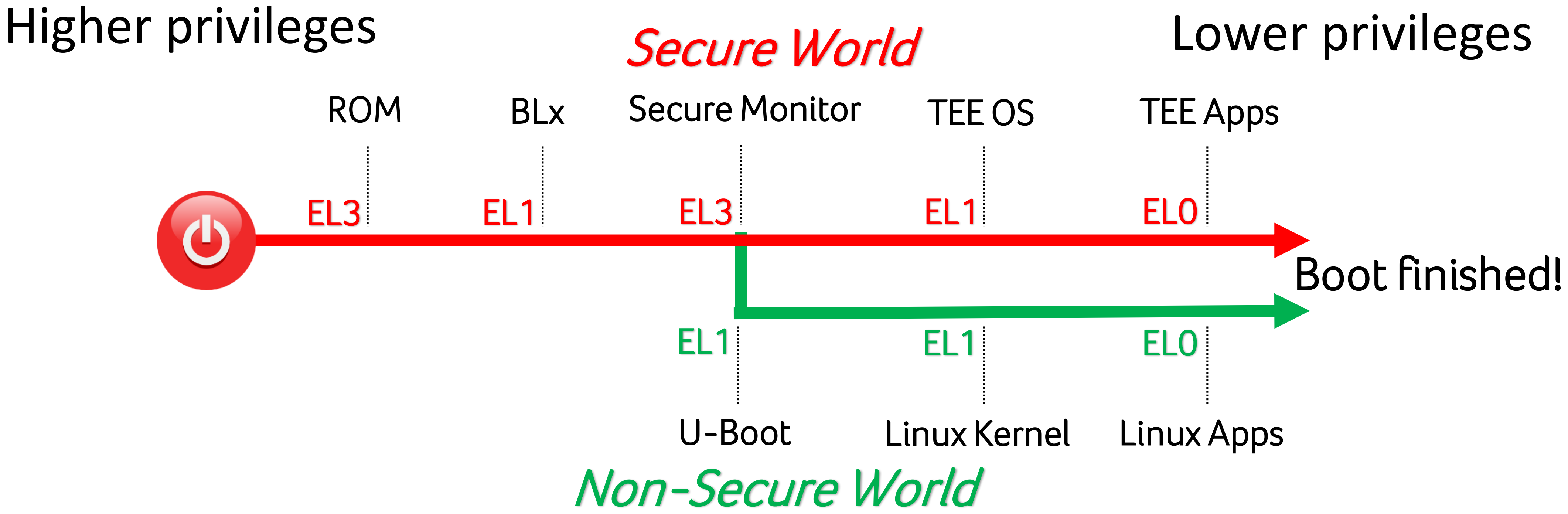

The chain can break at any stage. Earlier is better!

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- Security features often not initialized yet
  - e.g. access control
- Access assets that are not accessible after a certain stage
  - e.g. ROM code and keys

Why use Fault Injection on Secure Boot?

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Software vulnerabilities not guaranteed to be present!

Fault injection setup

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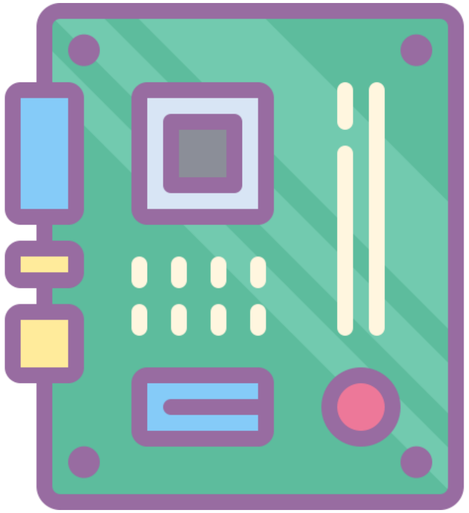

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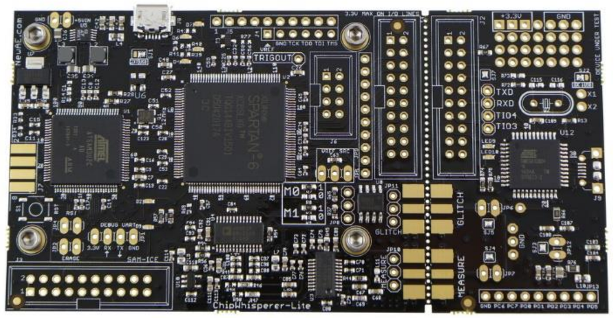

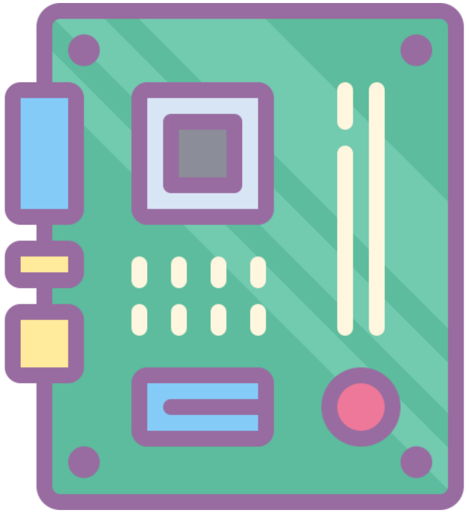

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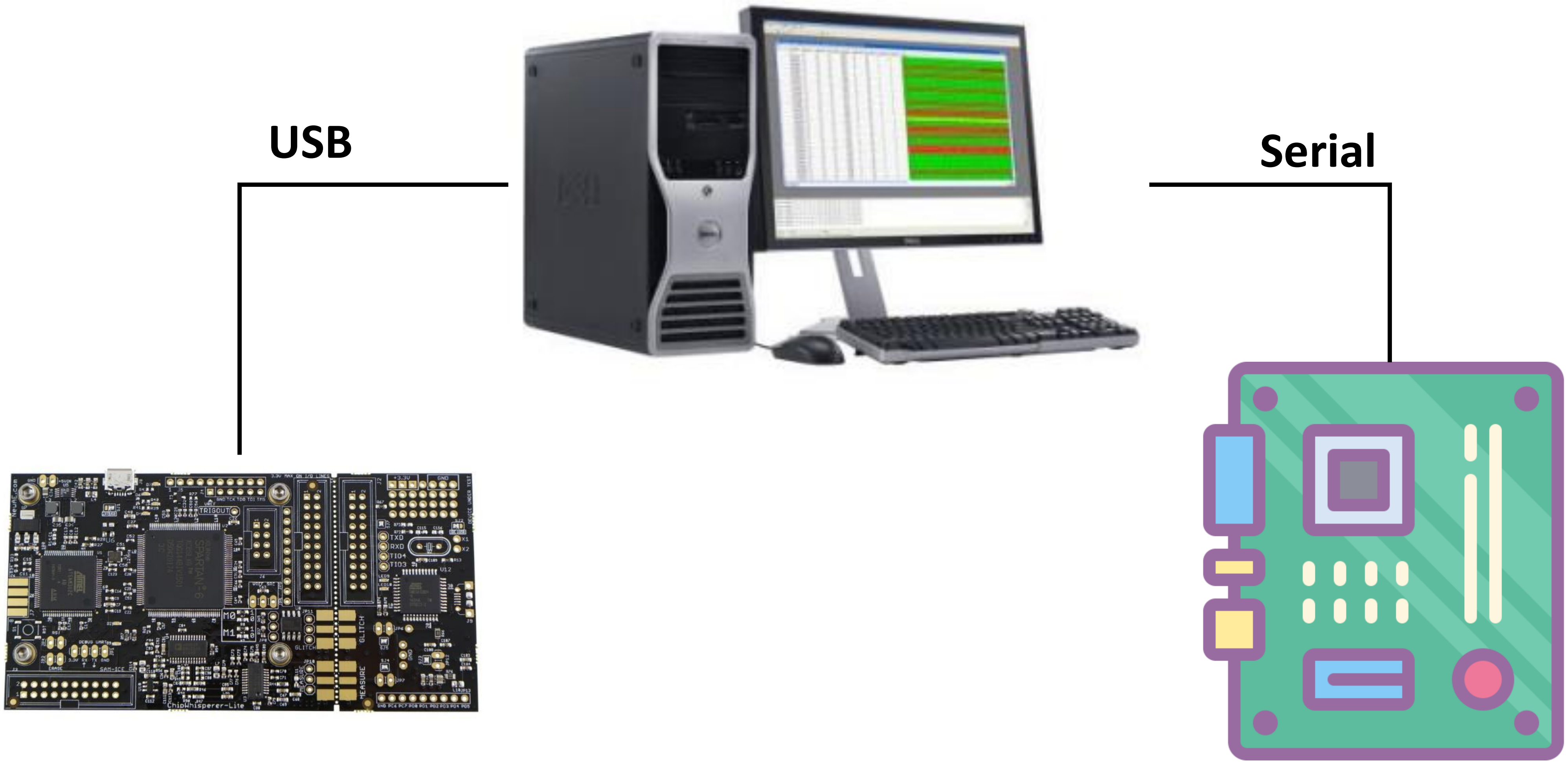

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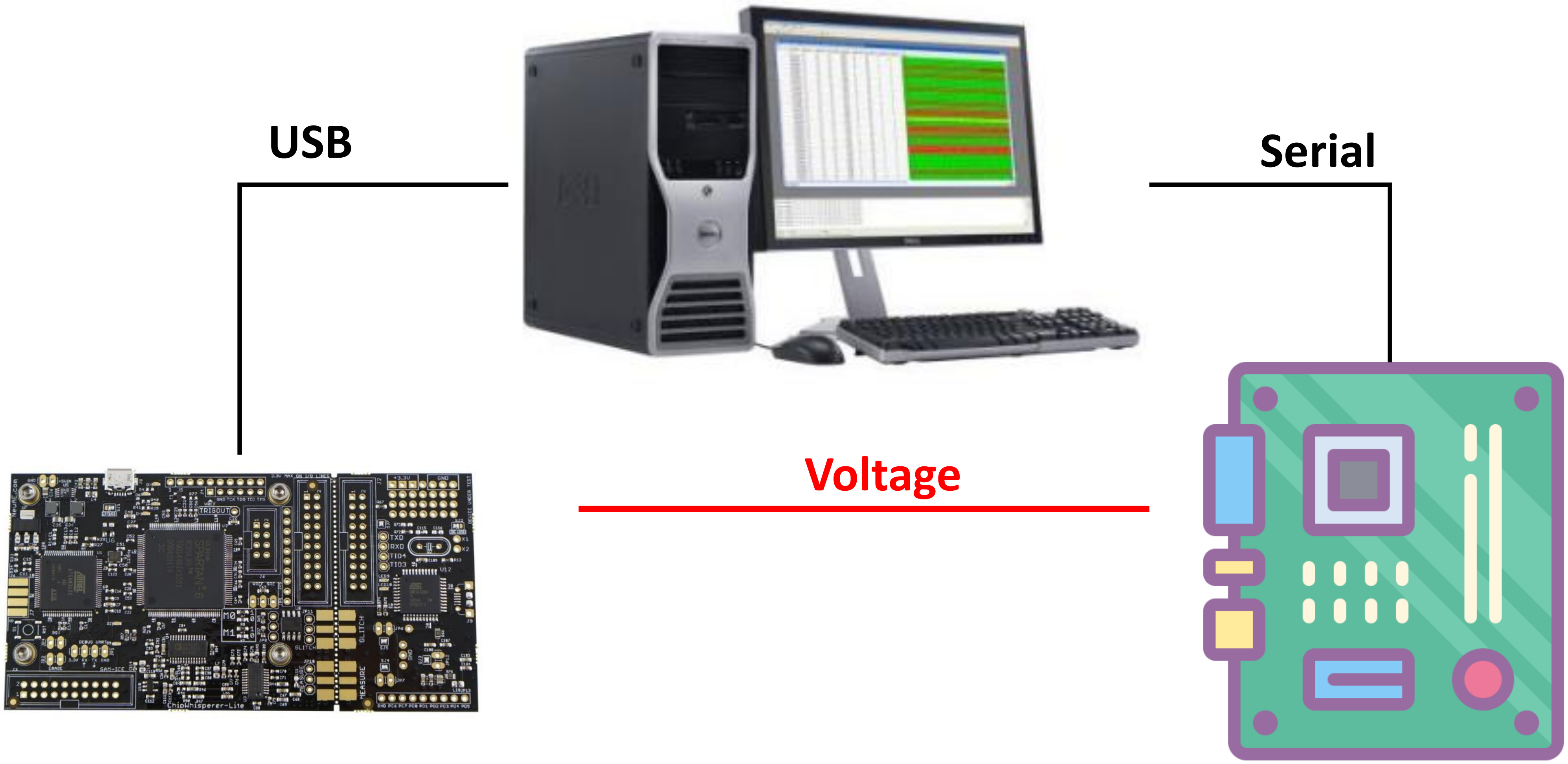

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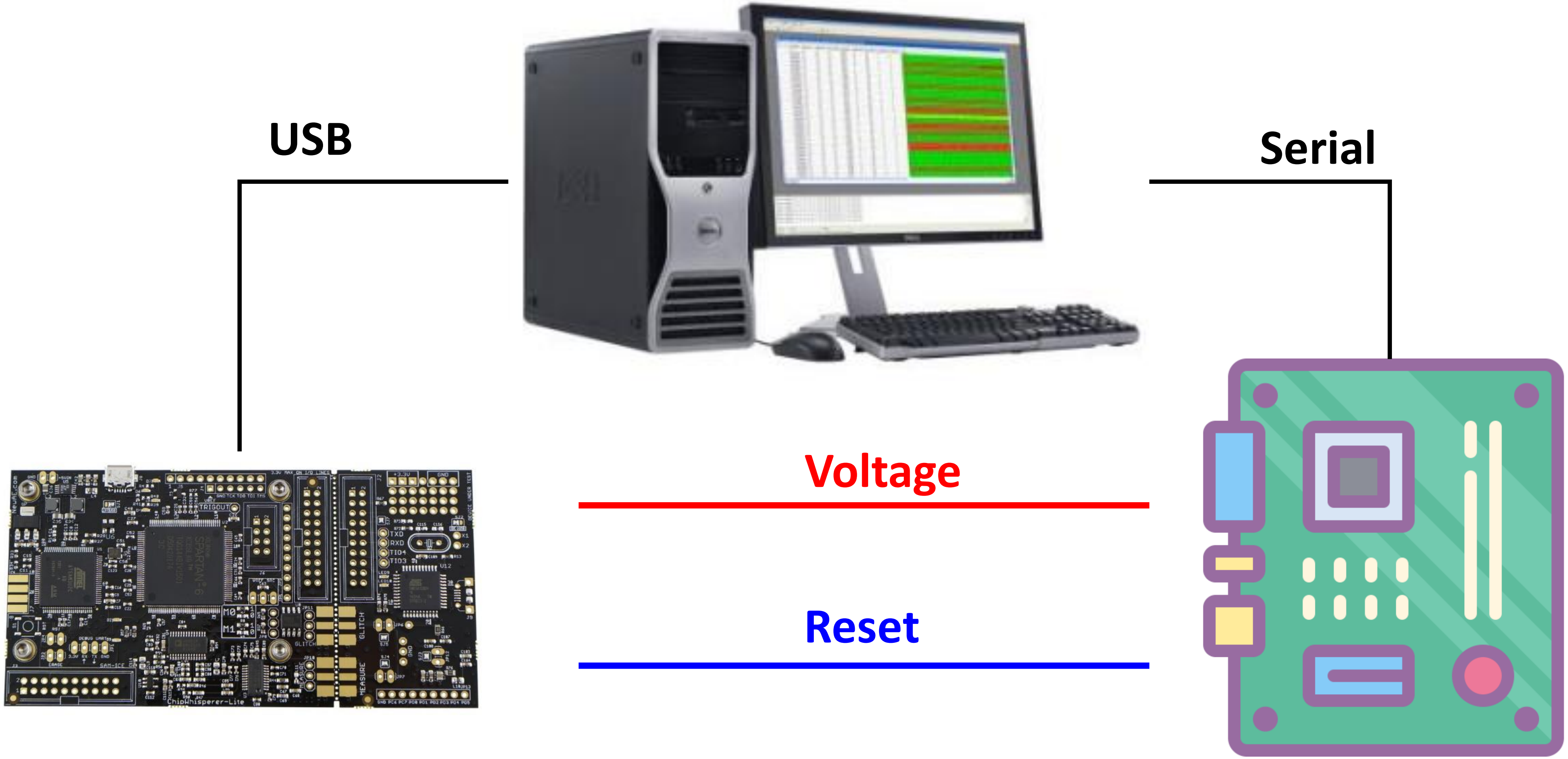

Signature verification

```
memcpy(I_SRAM, I_FLASH, I_SIZE);                    // 1. Copy image
memcpy(S_SRAM, S_FLASH, S_SIZE);                    // 2. Copy signature

if (*(OTP_SHADOW) >> 17 & 0x1) {                    // 3. Check if enabled
    if(SHA256(I_SRAM, I_SIZE, I_HASH)) {            // 4. Calculate hash
        while(1);
    }

    if(verify(PUBKEY, S_SRAM, I_HASH)) {            // 5. Verify image
        while(1);
    }
}

jump();                                             // 6. Jump to next image
```

How do we attack?

Fault Injection Fault Model: *“Instruction skipping.”*

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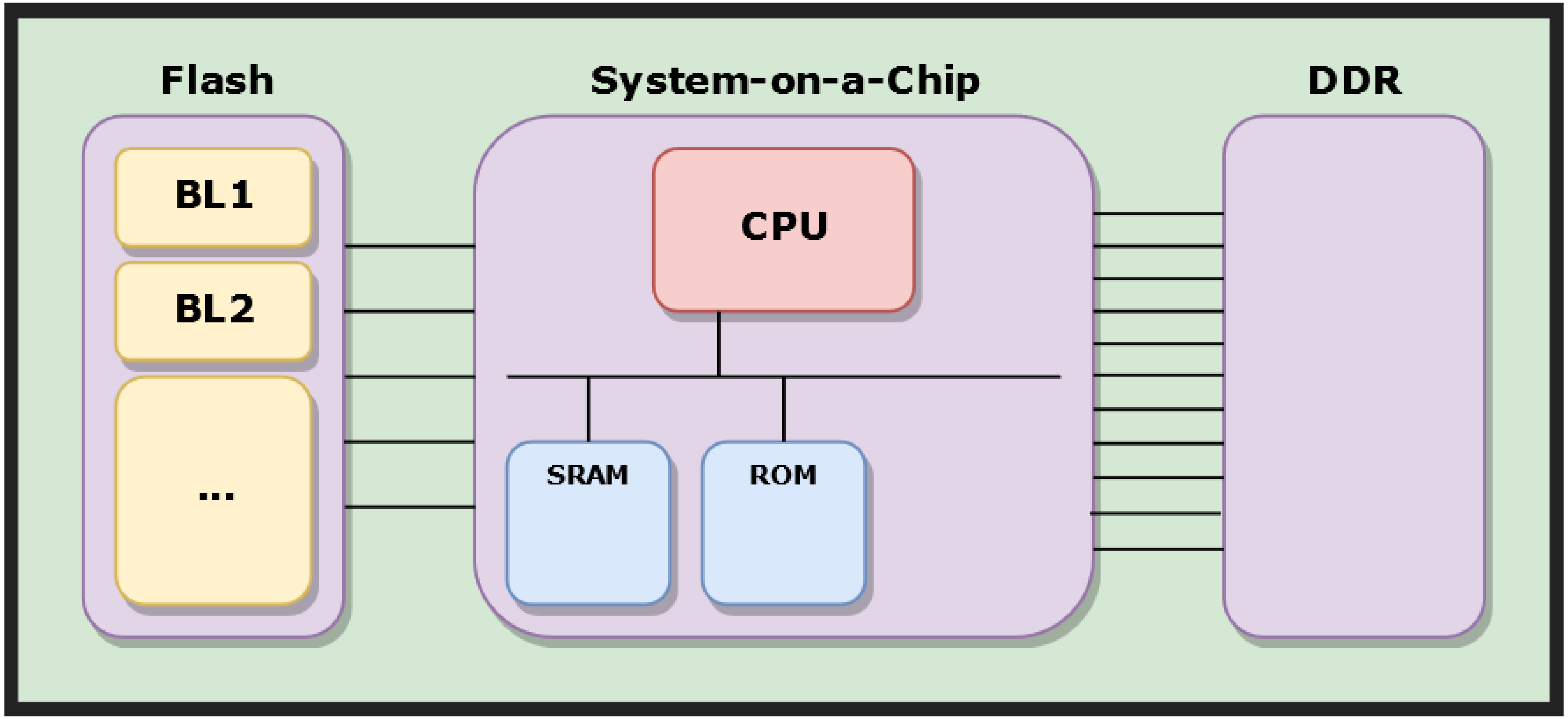
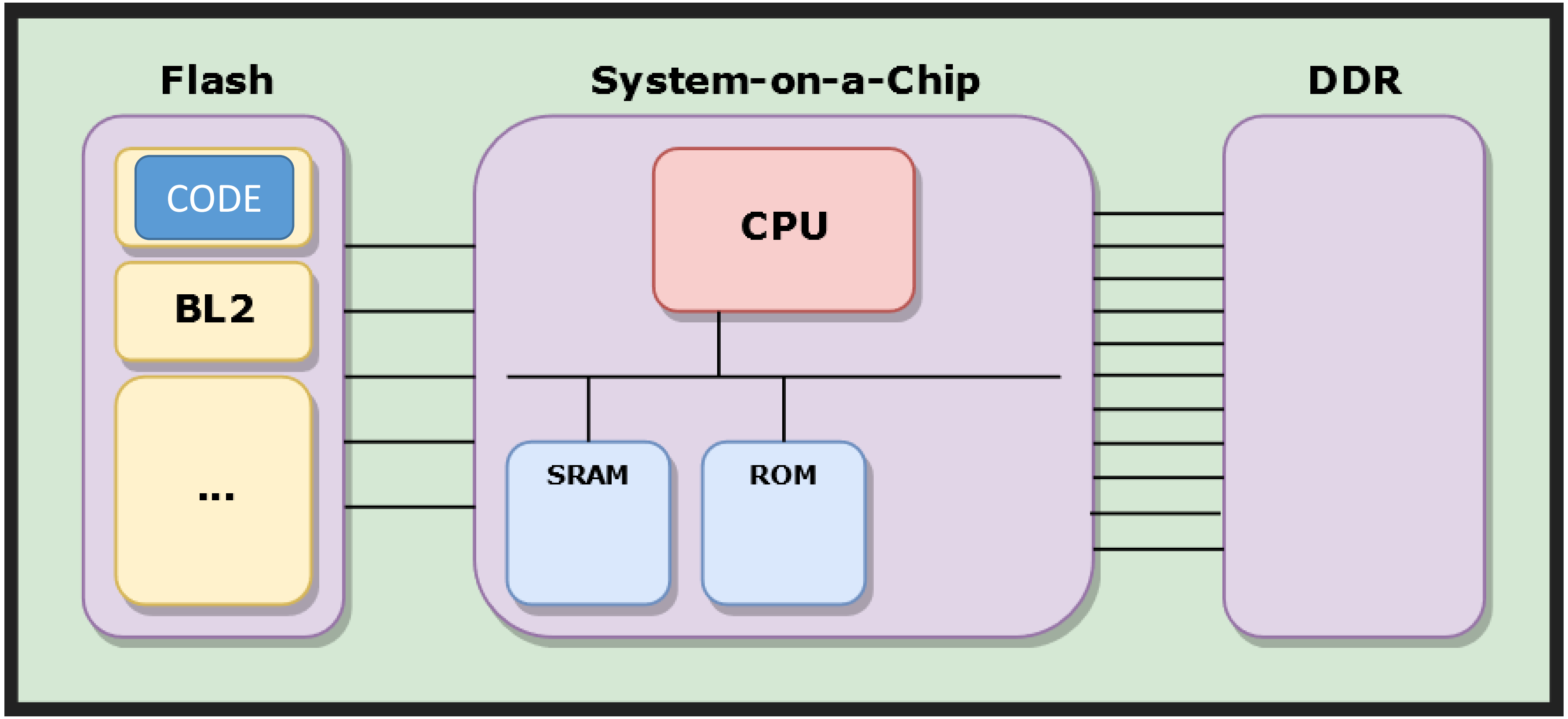
Cristofaro will dive much deeper into fault models!

Let’s use it to bypass Secure Boot!

Textbook Fault Injection Attack 1/4



Textbook Fault Injection Attack 2/4



Textbook Fault Injection Attack 3/4

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        while(1);
    }

    if(verify(PUBKEY, S_SRAM, I_HASH)) {
        while(1);                                   // 5. Glitch here!
    }
}

jump();                                             // 6. Jump to next image
```

Textbook Fault Injection Attack 4/4

```
103ec:  e59f3020    ldr r3, [sp, #32]
103f0:  e5933000    ldr r3, [r3]
103f4:  e59f201c    ldr r2, [sp, #28]
103f8:  e1530002    cmp r3, r2                  // if conditional
103fc:  1a000000    bne 10404 <func+0x20>
10400:  eafffffe    b   10400 <func+0x1c>   // endless loop
10404:  ebffffef    bl  103c8 <jump>            // jump to next image
```

Textbook Fault Injection Attack 4/4

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10404:   ebffffef    bl  103c8 <jump>            // jump to next image
```

Complete bypass of Secure Boot!

Let’s attack something else…

Escalating Privileges in Linux using Voltage Fault Injection

Niek Timmers
Riscure – Security Lab
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Cristofaro Mune
Embedded Security Consultant
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Paper / Presentation / Video (2017)

Target

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- Fast and feature rich System-on-Chip (SoC)

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- ARM Cortex-A9 (AArch32) @ ~ 1 GHz
- Ubuntu 14.04 LTS (fully patched)

Application vs Kernel

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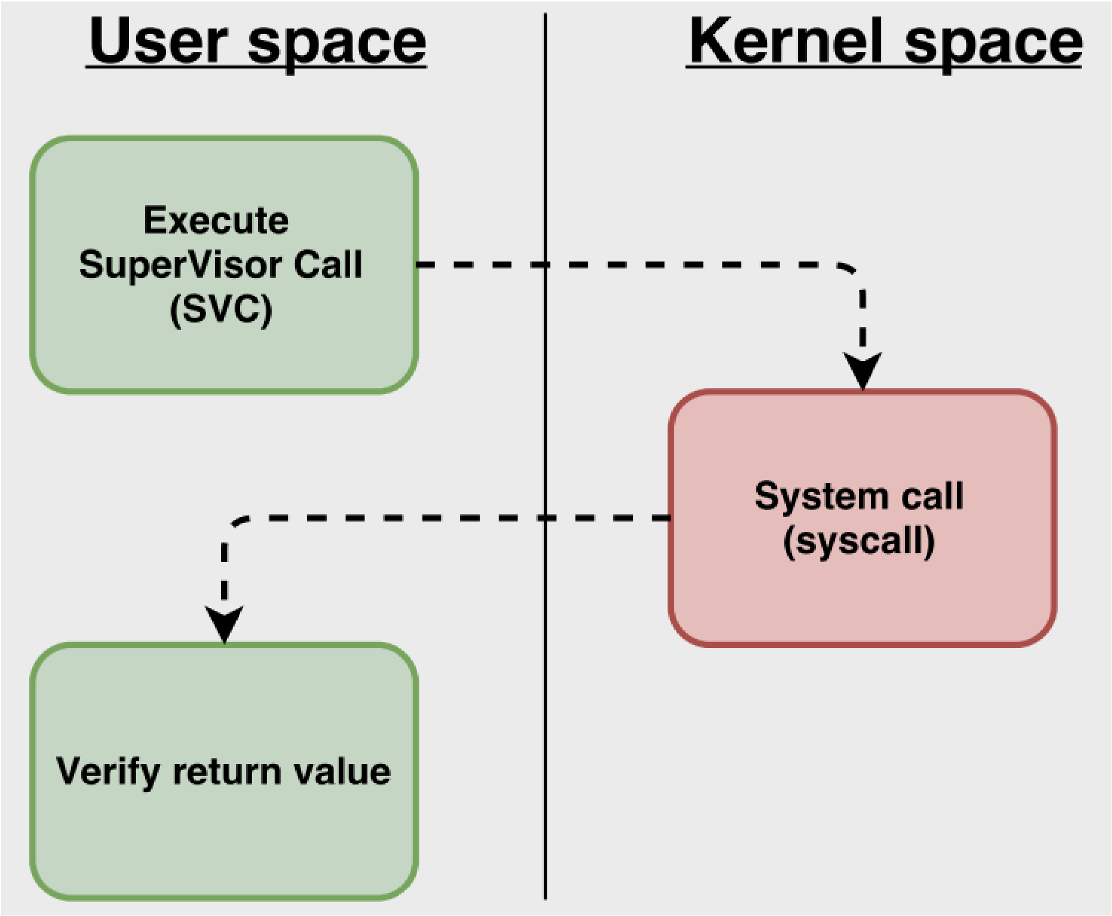
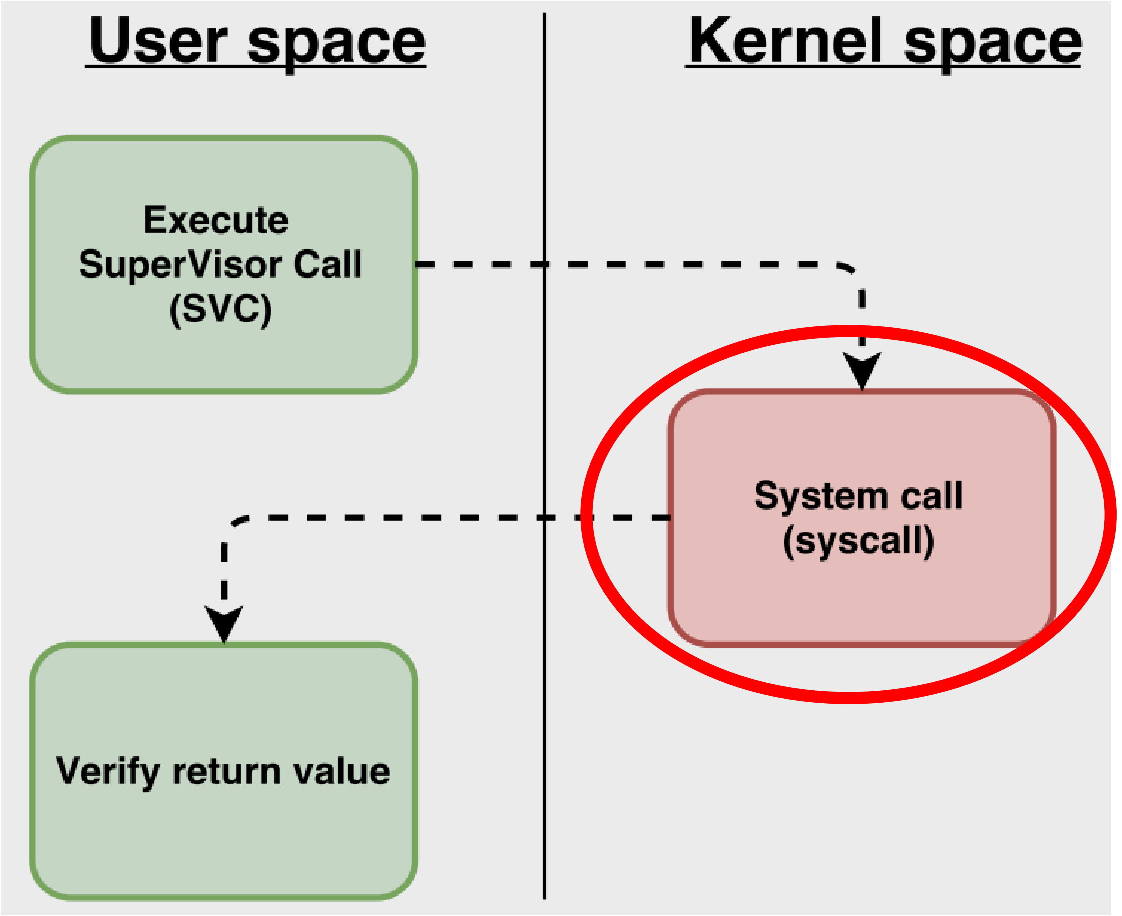
We assume the attacker can execute code as user without privileges



Application vs Kernel

We assume the attacker can execute code as user without privileges

The Kernel perform checks for security critical syscalls which will be the target for our attacks



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2. *Bypass checks performed by Linux kernel using a glitch*

3. Map arbitrary physical address in userspace

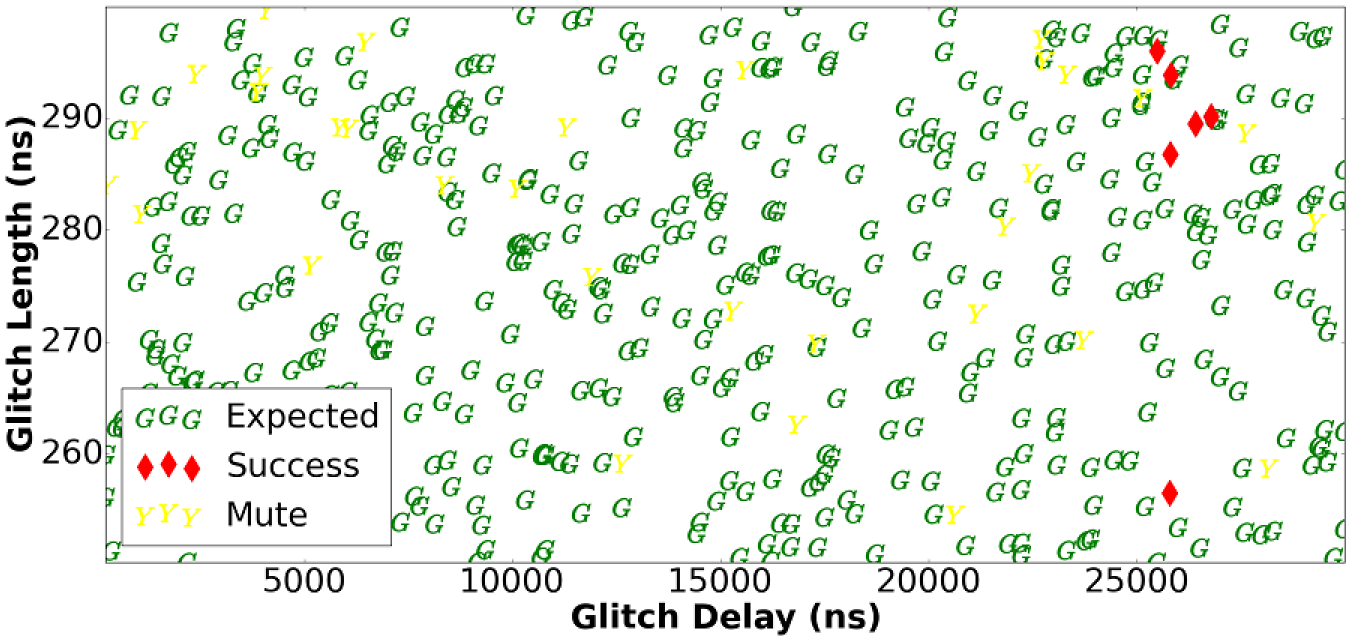
A successful glitch gives **(unrestricted) access to Kernel memory**!

Attack code for mapping arbitrary memory

```
*(volatile unsigned int *)(trigger) = HIGH;

int mem = open("/dev/mem", O_RDWR | O_SYNC);

*(volatile unsigned int *)(trigger) = LOW;

if( mem == 4 ) {
  void * addr = mmap ( 0, ..., ..., mem, 0);
  printf("%08x\n", *(unsigned int *)(addr));
}
. . .
```

- Code is running in user space
- Linux syscall: sys_open (0x5)

Results for mapping arbitrary memory



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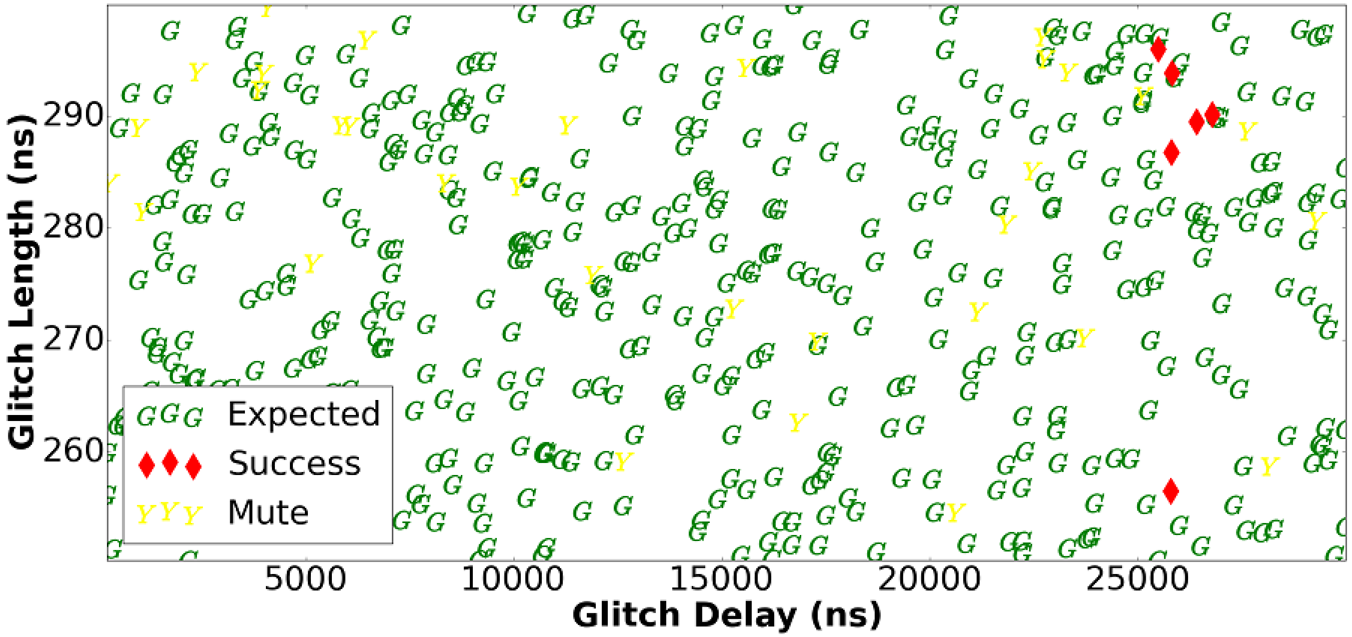

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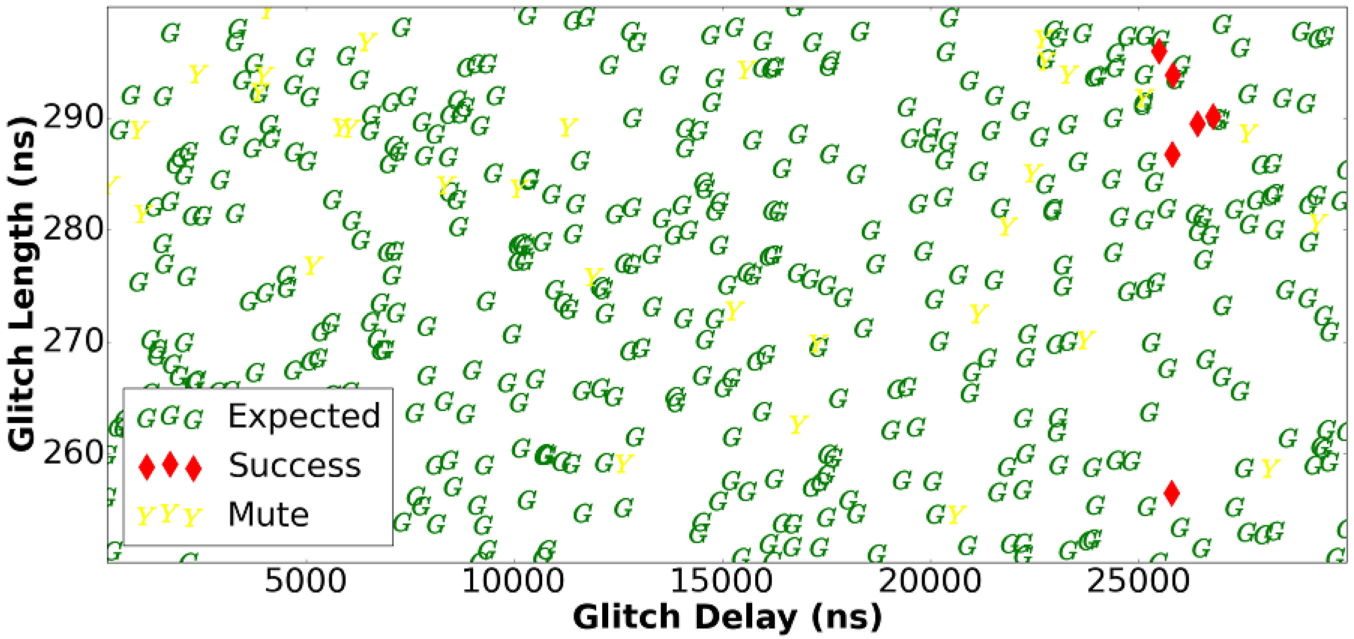
Results for mapping arbitrary memory



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- Success rate between 25.5 µs and 26.8 µs: 0.53%

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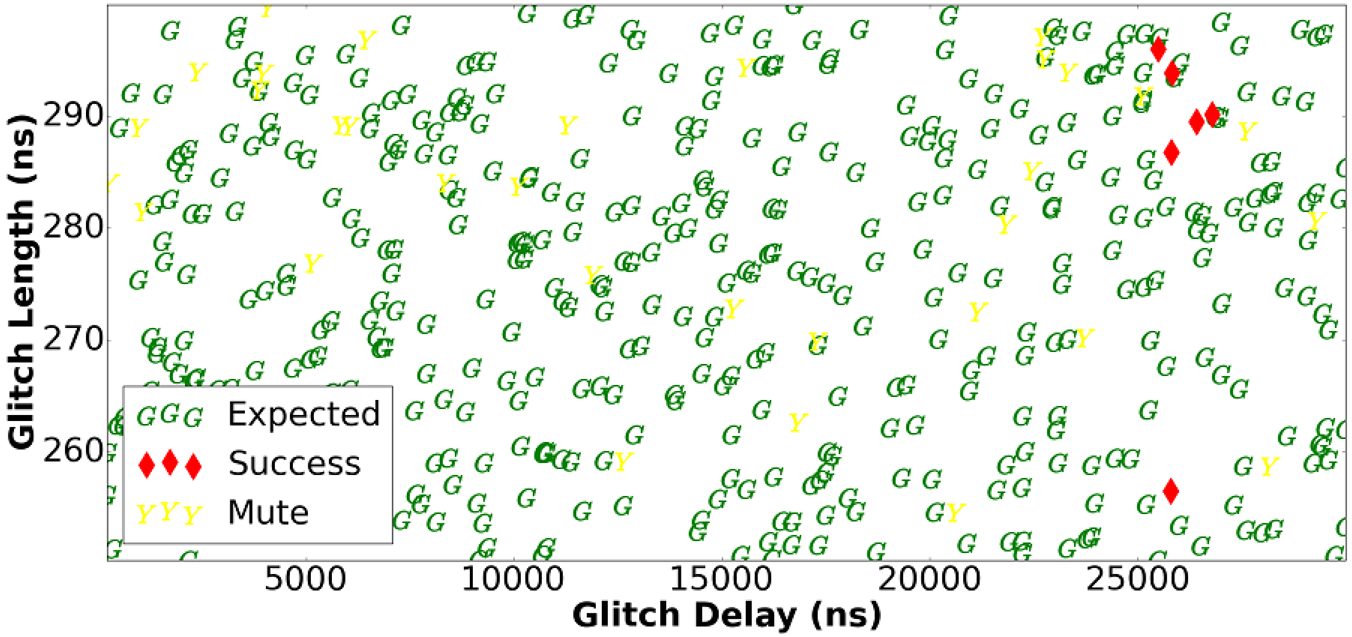

- Performed 22118 experiments in 17 hours
- Success rate between 25.5 µs and 26.8 µs: 0.53%
- ***Kernel "pwned" every 10 minutes***

What about popping a root shell directly?

Attack #2: Popping a root shell directly

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Attack #2: Popping a root shell directly

1. Set all CPU registers to 0 to increase success probability
2. Perform ***setresuid*** syscall to set process IDs to root
3. Bypass checks performed by Linux kernel using a glitch
4. Execute shell using ***system*** function

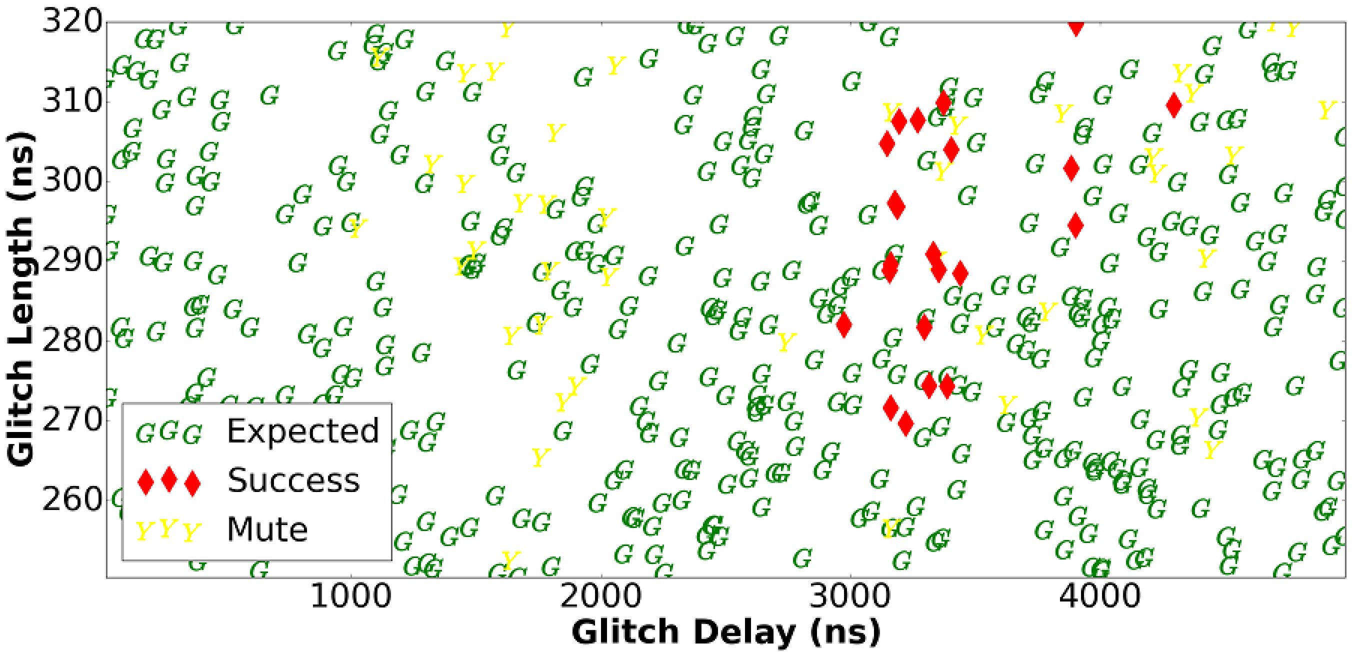
A successful glitch gives a **shell with root privileges**!

Attack code for popping a root shell directly

```
*(volatile unsigned int *)(trigger) = HIGH;

asm volatile (
  "movw r12, #0x0;" // Repeat for other
  "movt r12, #0x0;" // unused registers
  . . .
  "mov r7, #0xd0;"  // setresuid syscall
  "swi #0;"         // Linux kernel takes over

  "mov %[ret], r0;" // Store return value in r0
  : [ret] "=r" (ret) : : "r0", . . ., "r12" )

*(volatile unsigned int *)(trigger) = LOW;

if(ret == 0) { system("/bin/sh"); }
```

- Code is running in user space
- Linux syscall: setresuid (0xd0)

Results for popping a root shell directly



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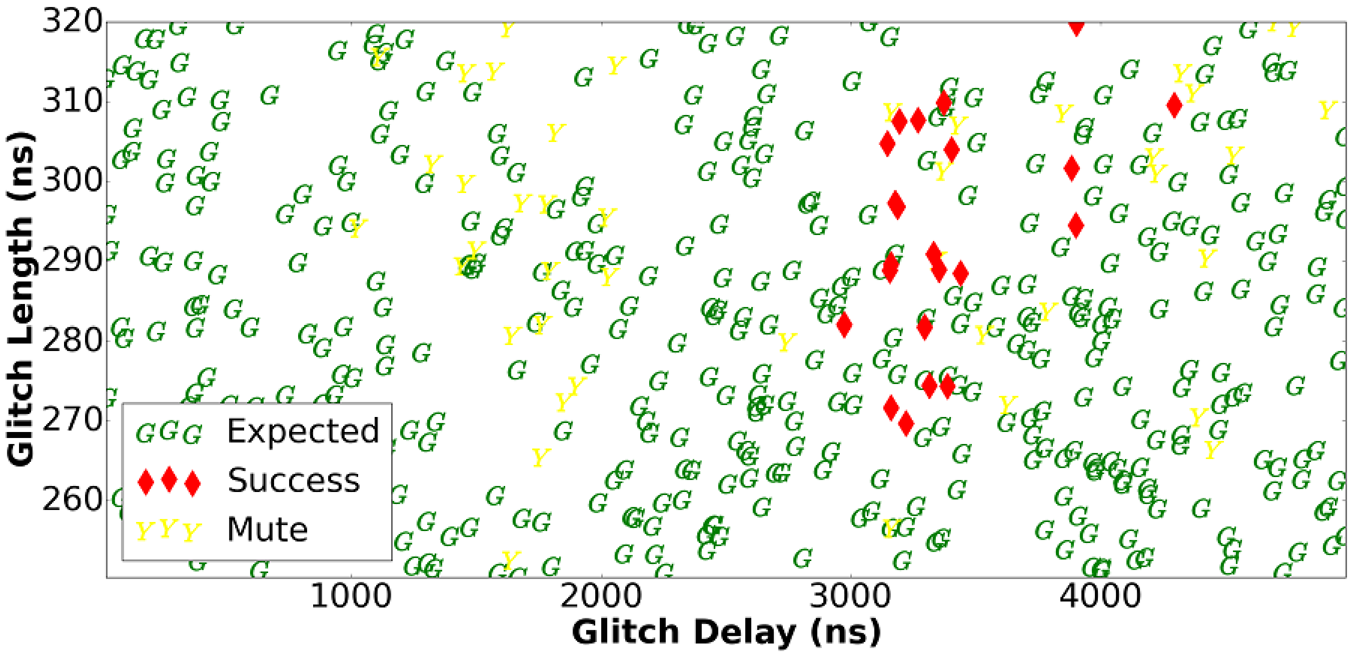

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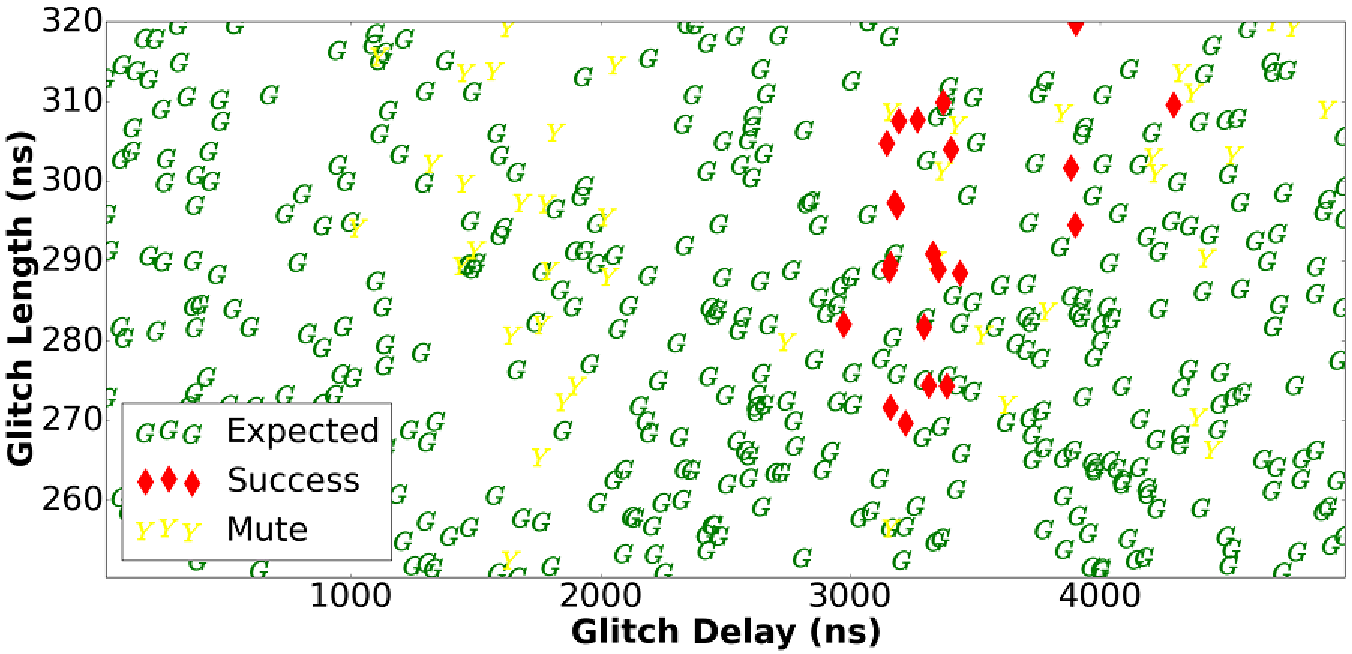

- Performed 18968 experiments in 21 hours
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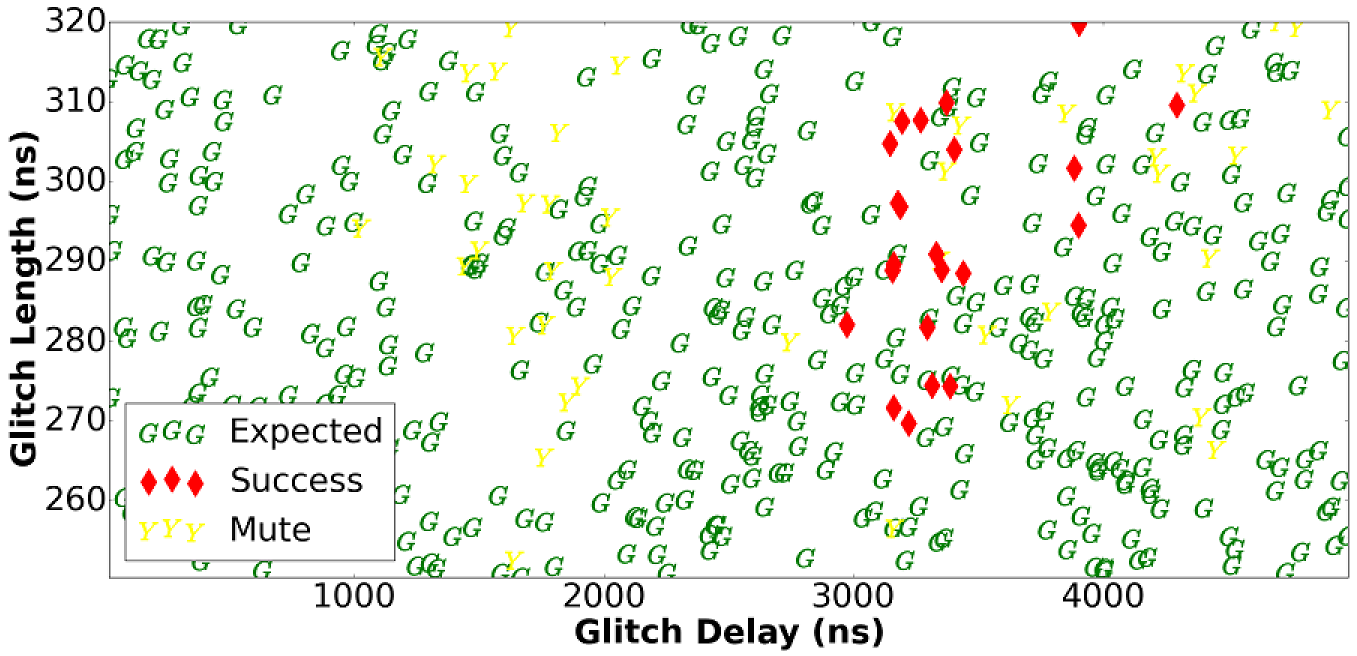

- Performed 18968 experiments in 21 hours
- Success rate between 3.14 µs and 3.44 µs: 1.3%
- ***Root shell "popped" every 5 minutes***

What about controlling the Program Counter (PC) in Kernel mode directly?!

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Controlling PC on ARM using Fault Injection

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Marc Witteman
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Delft, The Netherlands
witteman@riscure.com

Paper / Presentation (2016)

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1. Set all registers to a specific value (e.g. 0x41414141)

2. Execute random Linux system calls

3. Load an controlled value into the PC register using a glitch

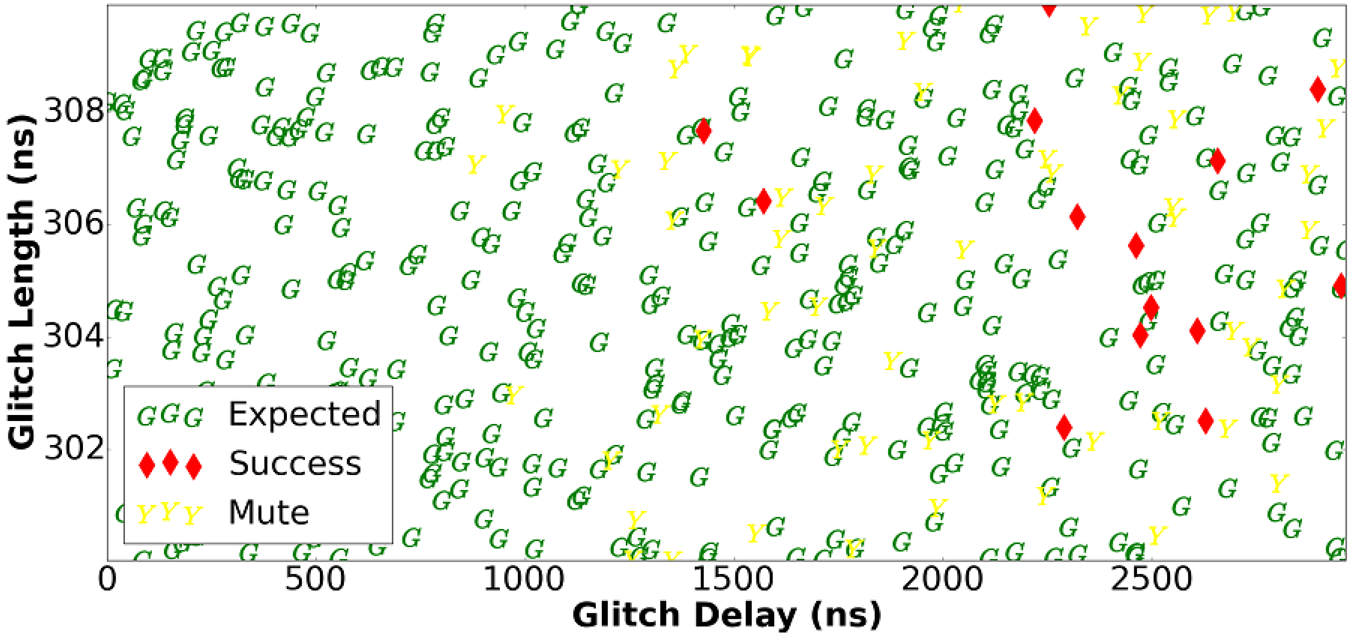
A successful glitch will **hijack the control flow**!

Attack code for controlling PC directly

```
. . .

*(volatile unsigned int *)(trigger) = HIGH;

volatile (
  "movw r12, #0x4141;" // Repeat for other
  "movt r12, #0x4141;" // unused registers
  . . .
  "mov r7, %[rand];" // Random syscall nr
  "swi #0;"          // Linux kernel takes over
  . . .

*(volatile unsigned int *)(trigger) = LOW;
. . .
```

- Code running in userspace
- Linux syscall: initially random
- We found **getgroups** and **prctl** to be more effective

Results for controlling PC directly



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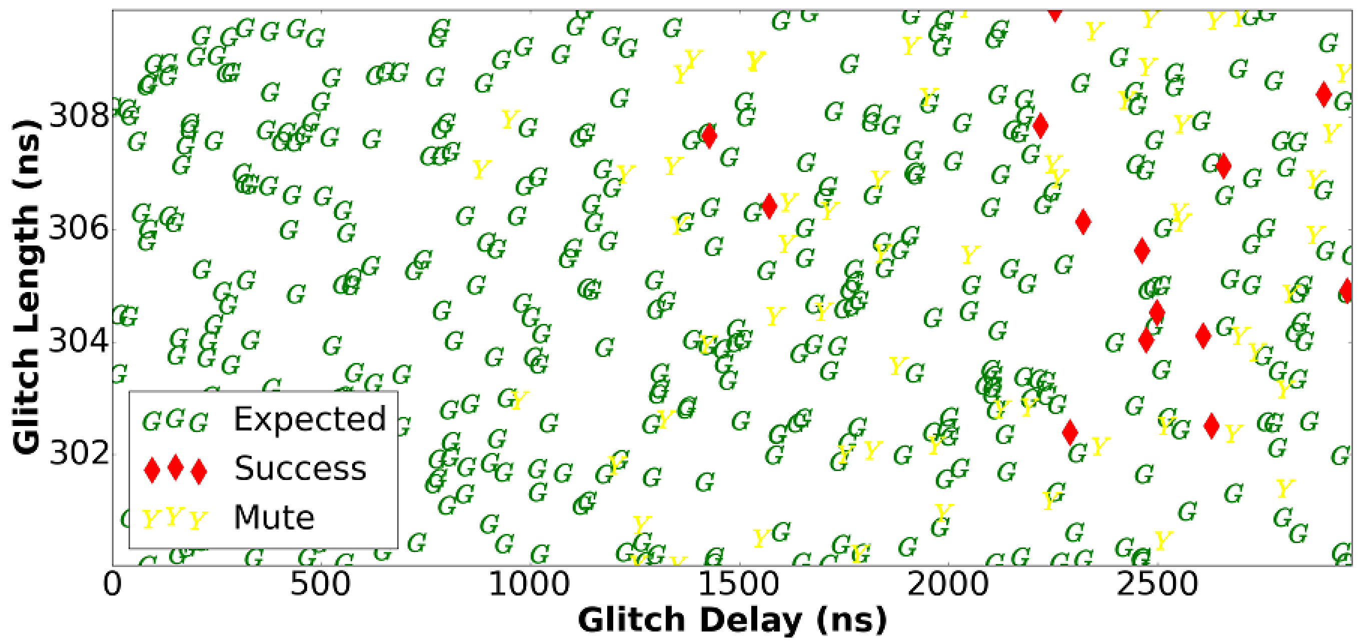
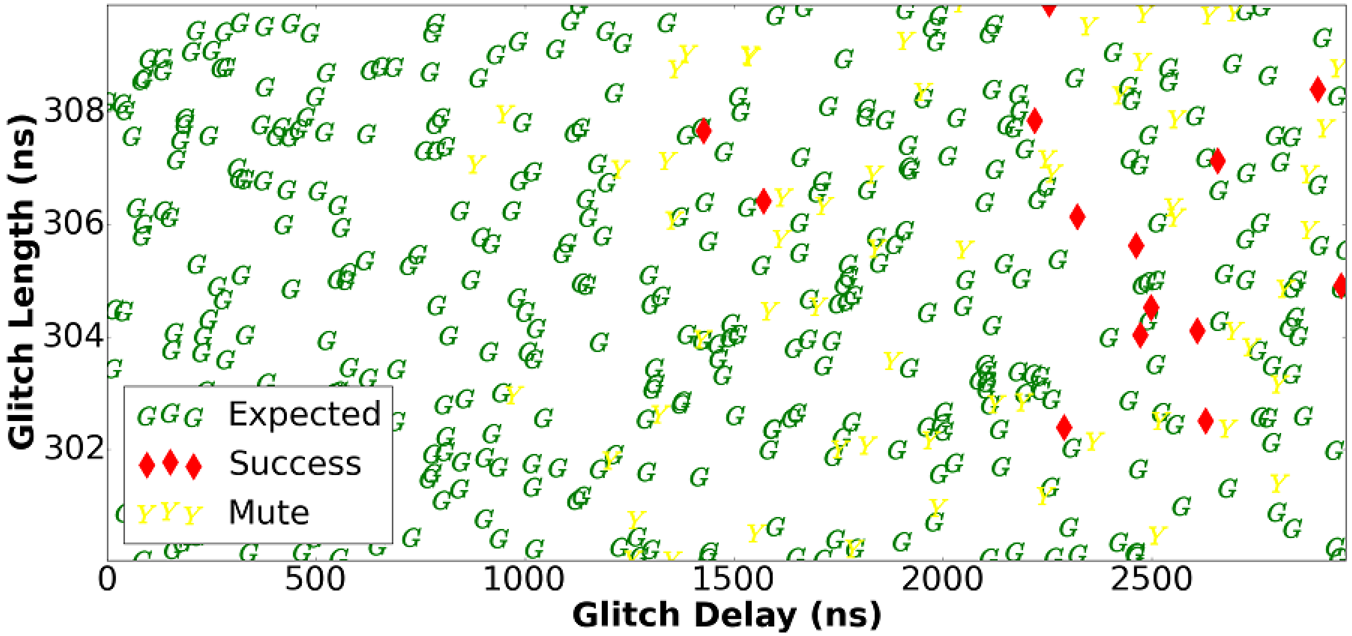


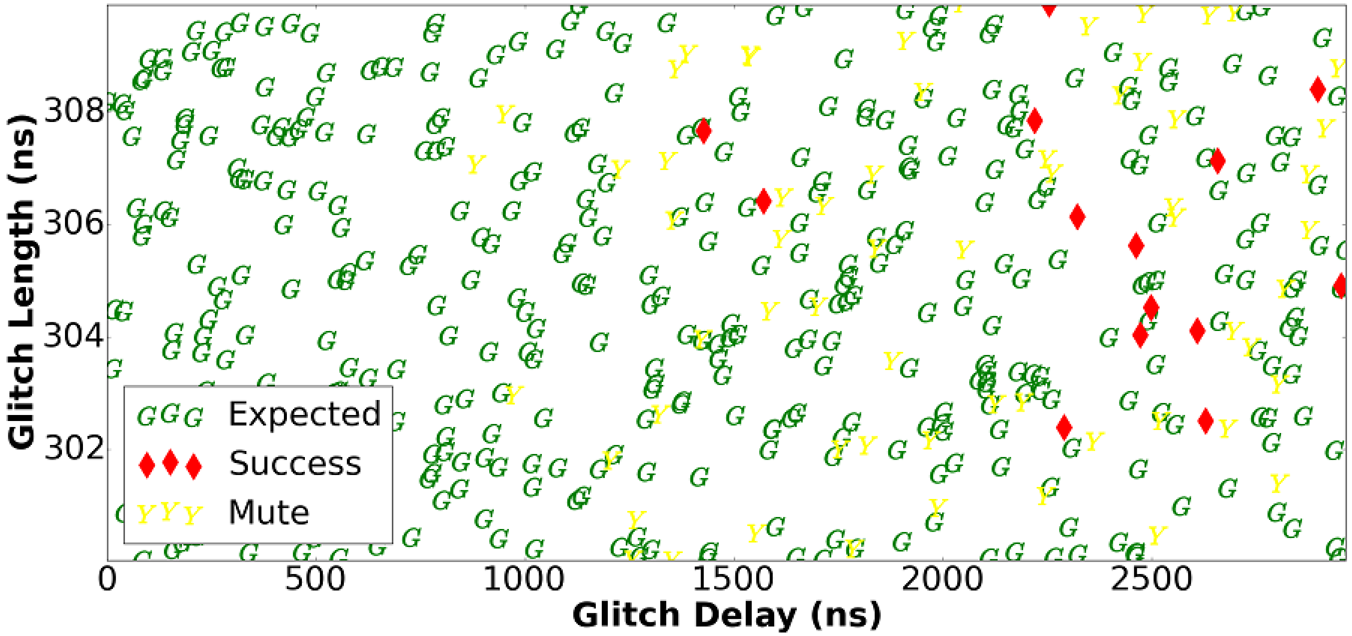
- Performed 12705 experiments in 14 hours

Results for controlling PC directly



- Performed 12705 experiments in 14 hours
- Success rate between 2.2 µs and 2.65 µs: 0.63%

Results for controlling PC directly



- Performed 12705 experiments in 14 hours
- Success rate between 2.2 µs and 2.65 µs: 0.63%
- ***Control of PC in Kernel mode gained every 10 minutes***

This is magic! Why does this work?

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You will hear that in the **next** sessions…

To conclude…

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  (it will not go away)

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  (adjust your threat model)

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- Fault injection practical and available to the masses
  (it will not go away)

- They can easily subvert typical software security models
  (adjust your threat model)

- Most standard devices are vulnerable
  (factor in countermeasures from the start)

Thank you! Any questions?!