CRYPTOGRAPHY AND CAMERA HOMEBREW

Running code on ARM with lenses

TLP:GREEN

BIO

Laurent Clévy

- Forensic analyst in a SOC/CERT + some reverse engineering
- Following Magic Lantern (aka ML) activity since years
- Wanna be low level reverser
- Twitter: @lorenzo2472, Github: https://github.com/lclevy

Free time contributions

- Canon RAW v2 and RAW v3 file formats reference documentations
- Ported ML on 550d and 60d. Experiments on my R6
- Reversed Original Data Decision implementation from Canon in 2012, with python tool to recompute signatures. See this MISC article (open access): https://connect.ed-diamond.com/MISC/mischs-006/mecanisme-de-controle-d-authenticite-des-photographies-numeriques-dans-les-reflexes-canon
- Other MISC MAG articles

DIGITAL CAMS ARE COMPUTING DEVICES

Digital Single Lens Reflex (DSLR) or Mirrorless Interchangeable Lens (MILC) cameras are complex devices

- Multiples CPUs (main, AF, peripherals, GPU, face recognition, network ops, …)
- ARM-A9, ARM-M4 (mpu), Tensilica Xtensa (net), Takumi GV550 (gpu)
- RTOS (DryOS)
- Wifi, Bluetooth, Ethernet, GPS, USB, HDMI
- RAW image processing at 10-30 frame/sec

Solution : dedicated System on Chip for Canon, called DigIC (Digital IC)

So hackers want to run Doom on it !

https://www.youtube.com/watch?v=fAoIjXZYu70 (Doom on RP by @coon)

https://wiki.magiclantern.fm/digic (which CPUs per Digic generation)

STANDING ON GIANTS SHOULDERS

CHDK, Canon Hack DevKit (pocket cameras)

- https://chdk.fandom.com/wiki/CHDK
- Enhancing official firmware
  - RAW, LUA scripting,…
  - Loaded from sdcard, only in memory

Magic Lantern (DSLR)

- Created by Trammell Hudson (https://trmm.net/Magic_Lantern_firmware/)
  - Code execution in may 2009 on 5Dm2, with modified FIR update file
  - But blocked by signature check activation on 7D,
- 2010-2018 main contributors: A1ex (main dev), G3gg0 (reverse), Arm.Indy (crypto), …
- 2018-2022 : Kitor (reverse+dev), Names_are_hard, Coon, Petabyte, Turtius, …

FIR FILES (VERSION 4, 2007-2018)

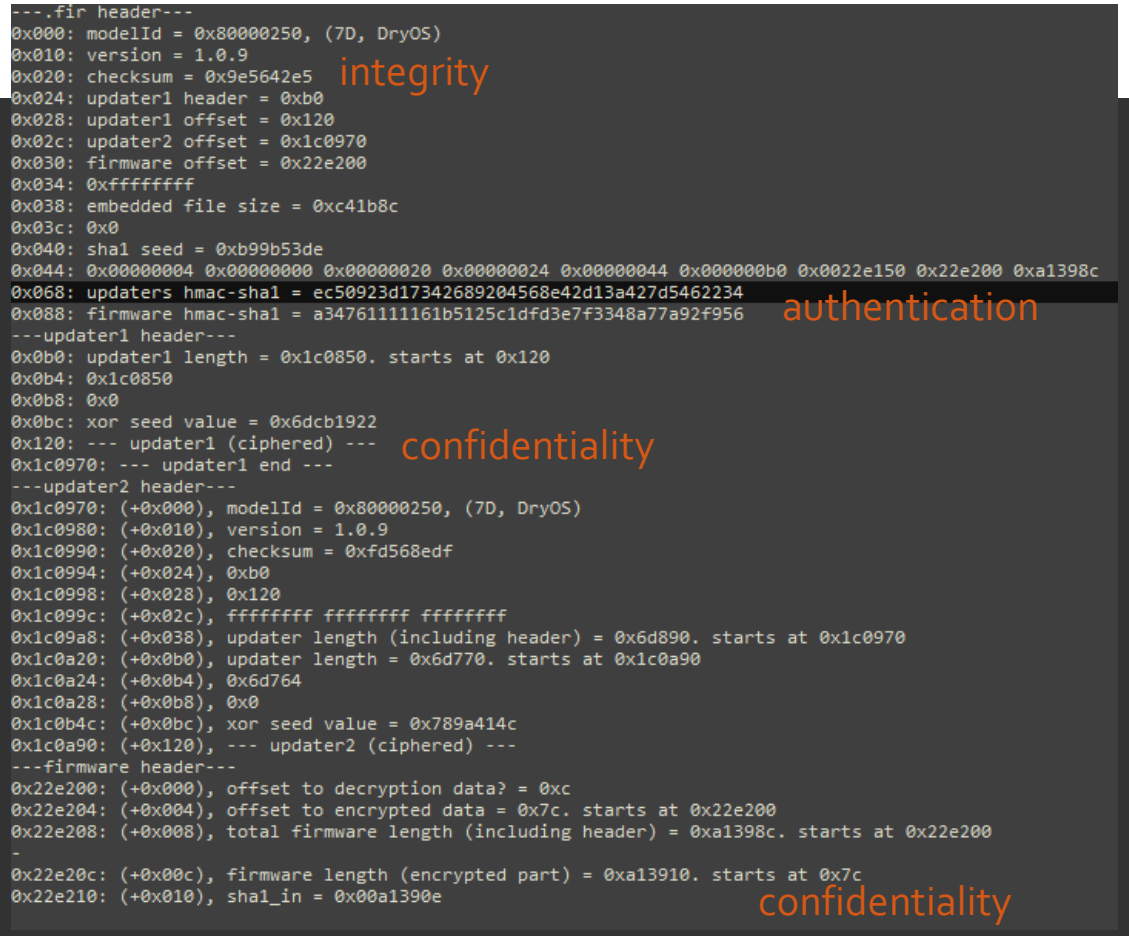
FIR header
- Camera model
- Update version
- FIR file checksum (sum of bytes)
- Pointers to other sections (updater1, 2, 3, and fw records)
- Signature header (how to compute updaters signature)
- Updaters signature value (hmac-sha1)
- Firmware records signature value (hmac-sha1)

Updater1 header
- Encryption header
- Encrypted payload (AES)

…

Firmware header
- Encrypted header
- Encrypted payload (AES)

See
- https://groups.google.com/g/ml-devel/c/ASabsRbvgvQ/m/IKsMn3PPqPQJ?hl=en%7C7D (Trammell, 10/2009)
- https://magiclantern.fandom.com/wiki/Firmware_file (Indy, 2011)



CODE EXECUTION : PATCHING UPDATER

40d (2007, VxWorks)

- Within update FIR file, updater code is only xored with 2 tables (512 and 513 bytes)
  - Updater is patched to dump memory (by ASalina, 2008)
  - Video hack based on liveview !
- Update records are AES encrypted

5dm2 (2008, DryOS)

- Bootflag activated by modified updater, then autoexec.bin loaded from sdcard
- Autoexec.bin : Canon feature likely for factory operations

7d (2009)

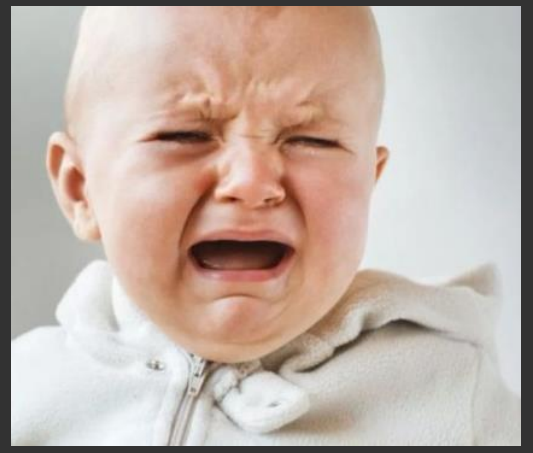
- Signature check activated. FIR Signature and decryption reversed (2010)
- ML team is able to forge FIR files (update files) like Canon, but Crypto tools kept private

550d (2010)

- Updater is now encrypted with AES too, and keys are changed

EOS R (09/2018) : CRYPTO CHANGED

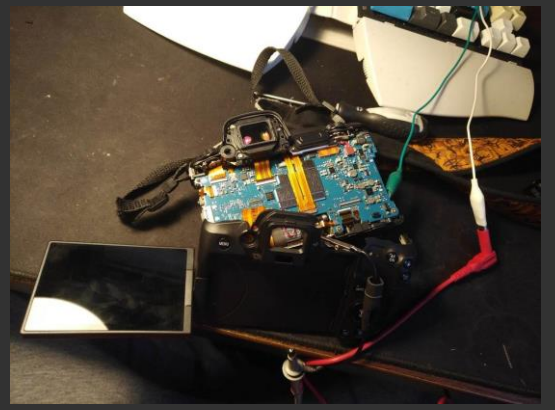
- FIR encryption changed, ML team can not decrypt Canon updates and reverse them for porting code
- FIR signature changed, no way to forge valid updates, run code to dump ROM
- No dumps, no reverse, no hacking !



EOS R, UART ACCESS

14/02/2019

- Kitor activated Bootflag via UART
- Custom autoexec.bin payload was used to dump
- Not suited to allow everyone to dump and port ML ☹



2/09/2020

- Free gift: Canon basic is available on EOS R !
- Discovered by Oren Isacson Alfredo Ortega, presented at DEFCON 18 (07/2010)
  - https://www.youtube.com/watch?v=ByuHcamy2Z4
- Known by CHDK people since 2010
  - https://chdk.setepontos.com/index.php/topic,5549.0.html
- Was not available on previous DSLRs, except m50 (04/2018)

CANON BASIC

Scripts can be executed under specific conditions

- See https://chdk.fandom.com/wiki/Canon_Basic

Format of the SD card

- The SD card may be in FAT16 or FAT32 format.
- The SD card must contain the following items:

1. The string "SCRIPT" must be at offset 0x1F0 of the first sector (Boot sector).
2. The file "script.req" must exist on the card's root directory, and must only contain the string "for DC_scriptdisk\n" (where the \n represents a newline character)
3. The file "extend.m" or "autotest.m" must exist on the root directory. This file must contain the Canon BASIC script to execute.

Scripts examples:

- Dump main ROM

```
private sub Initialize()
    SaveAllRomImageToFile()
end sub
```

- Enable Bootflag

```
EnableBootDisk()
```

- Dump camera log

```
dumpf()
```

```
buf = umalloc(0x1000)
if buf=0 then
    exit sub
end if
bufo = umalloc(0x1000)
if bufo=0 then
    ufree(buf)
    exit sub
end if
memset(bufo,0,0x1000)
f = OpenFileRD(cpuinf_binary)
FIO_ReadFile(f,buf,0x1000)
CloseFile(f)
ExportToEventProcedure("cpuinfo",buf|1)
cpuinfo(bufo)
```

- Allocate memory, load ARM code and jump to it with parameter !
  - See https://github.com/lclevy/cbasic_examples/blob/main/R6.150/extend_cpuinfo.m

P TP CANON EVENT PROCEDURES

Event procedures are "call by name" functions, works with PTP

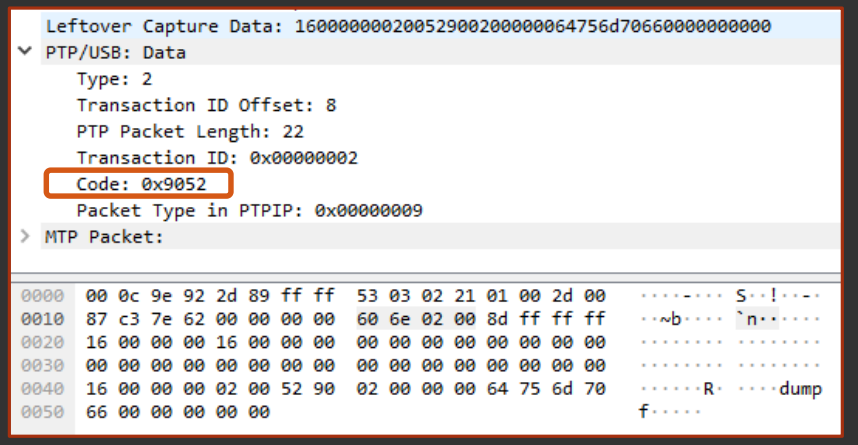
- Available from Canon Basic
- From DryOS, ARM code: call('enablebootdisk');
- From Picture Transfer Protocol, via a custom command : 0x9052

Petabyte (June 2021)

- Enabling bootflag using PTP on 1300D (digic4+)
- Reference client implementation is Canon EDSDK.DLL (from EOS UTILITY)

SRSA (06/02/2022)

- Describe EventProcedure call encoding with parameters
- See https://chdk.setepontos.com/index.php?topic=4338.msg147738#msg147738



CODE EXEC PATH PER DIGIC GENERATIONS

Code exec method	40D 2007 (d3)	5Dm2 2008 (d4)	1300D 2016 (d4+)	5D3 2012 (d5)	80D 2016 (d6)	5Dm4 2016 (d6+)	6D2 2017 (d7)	M50 04/2018 (d8)	EOS R 09/2018 (d8)	R6 2020 (dx)	R10 2022 (dx)
Cbasic	no	no	no	no	no	no	no	ok	ok	ok	locked
Fir v4	yes	yes	yes	yes	yes	yes	yes	yes	no, v5	no, v6	?
autoexec	?	yes	yes	yes	yes	yes	yes	yes	yes	yes	?
ptp	no?	yes	yes	yes	yes	yes	yes	yes	locked	locked	locked
uart	no?	?	ok	ok	ok	yes	ok	ok	ok	ok	locked

Canon needs code execution in factories to personalize / calibrate cameras

- Cbasic, autoexec and PTP features do certainly exist for that

Imagination (and time) are the limits …

OTHER REFERENCES

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cpu=x86, mpu=mips, os=DOS
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Homebrew firmware for the 5D Mark 2, Trammell Hudson (17/05/2009)
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EOS firmware in QEMU - development and reverse engineering guide, A1ex
https://foss.heptapod.net/magic-lantern/magic-lantern/-/blob/branch/qemu/contrib/qemu/HACKING.rst

ML discord server : https://discord.gg/TyRPtvAS