An Amazing Journey into the depth of my Hard Drive

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About myself

- Master Thesis on security of Amazon EC2 machines
- PhD Candidate on the topic of Embedded Firmwares' Security at EURECOM [1]
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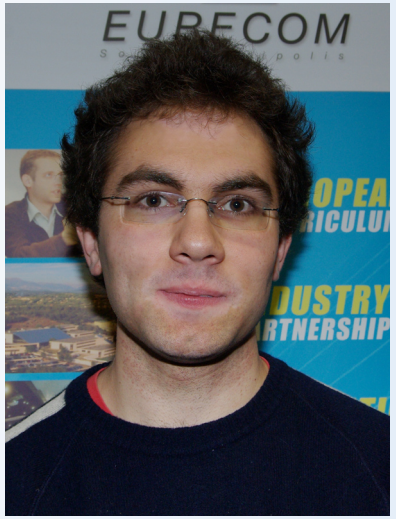


EURECOM
Sophia Antipolis

Acknowledgements

- Thanks to my Advisor Davide Balzarotti and “Co-Advisor” Aurélien Francillon for enabling me to do this research!
- Thanks to Travis Goodspeed for getting me started
- Similar hacking has been done by sprite_tm on a different HDD brand [3]
- A description of a sophisticated data exfiltration backdoor based on compromised HDDs [5]

What is a hard drive? – Physical view

- A bunch of magnetized disks that store binary information
- The heads move over those disks
- A DSP or custom chip decodes the analog signal
- A microprocessor handles communication with the PC and keeps components in sync

What is a hard drive? – Logical view

- Bytes are grouped into blocks (typically 512 bytes), which are addressed by a block number (LBA)
- The computer can (among other) read and write blocks
- Lots of care is taken that written blocks do not change (error correction, etc)

Breaking in

- There is a JTAG port, but it seems to be disabled :(
- Seagate drives have a diagnostic serial port accessible on the Master/Slave jumpers
- This feature is known and documented in professional circles (e.g., HDD recovery specialists [4])
- A text menu gives access to diagnostic functions
- This feature is not specific to Seagate (also found a similar menu in WD and Samsung disks)
- Type CTRL+Z on the serial console …

Diagnostic Firmware Menu

```
Online CR: Rev 0011.0000, Flash,   Abort
Online ESC: Rev 0011.0000, Flash,   Abort Looping Command
   or Batch File
Online ' ': Rev 0001.0000, Flash,   Pause Output
Online '.': Rev 0011.0000, Flash,   Display Active Status
Online '?': Rev 0011.0000, Flash,   Display Diagnostic
   Buffer Information
Online '`': Rev 0012.0001, Flash,   Display Read/Write
   Statistics
Online '$': Rev 0012.0002, Flash,   Display Read/Write
   Statistics By Zone
Online '{': Rev 0011.0000, Flash,   Toggle EIB-Specific
   R/W Tracing
```

Diagnostic Firmware Menu (2)

```
Online ^Z: Rev 0011.0000, Flash,   Enable ASCII Diagnostic
   Serial Port Mode
All Levels '+': Rev 0012.0000, Flash,   Peek Memory Byte,
   +[AddrHi],[AddrLo],[NotUsed],[NumBytes]
All Levels '-': Rev 0012.0000, Flash,   Peek Memory Word,
   -[AddrHi],[AddrLo],[NotUsed],[NumBytes]
All Levels '=': Rev 0011.0002, Flash,   Poke Memory Byte,
   =[AddrHi],[AddrLo],[Data],[Opts]
Online ^C: Rev 0011.0000, Flash,   Firmware Reset
```

Dumping the firmware

- Hmmm, we got peek and poke, that's cool
- With a bit of trial and error, the firmware can be extracted (drive will crash if you use invalid address)
- Neighborly thanks to Travis Goodspeed who dumped the firmware
- But it gets even more interesting … when you reboot the drive

Bootloader Prompt

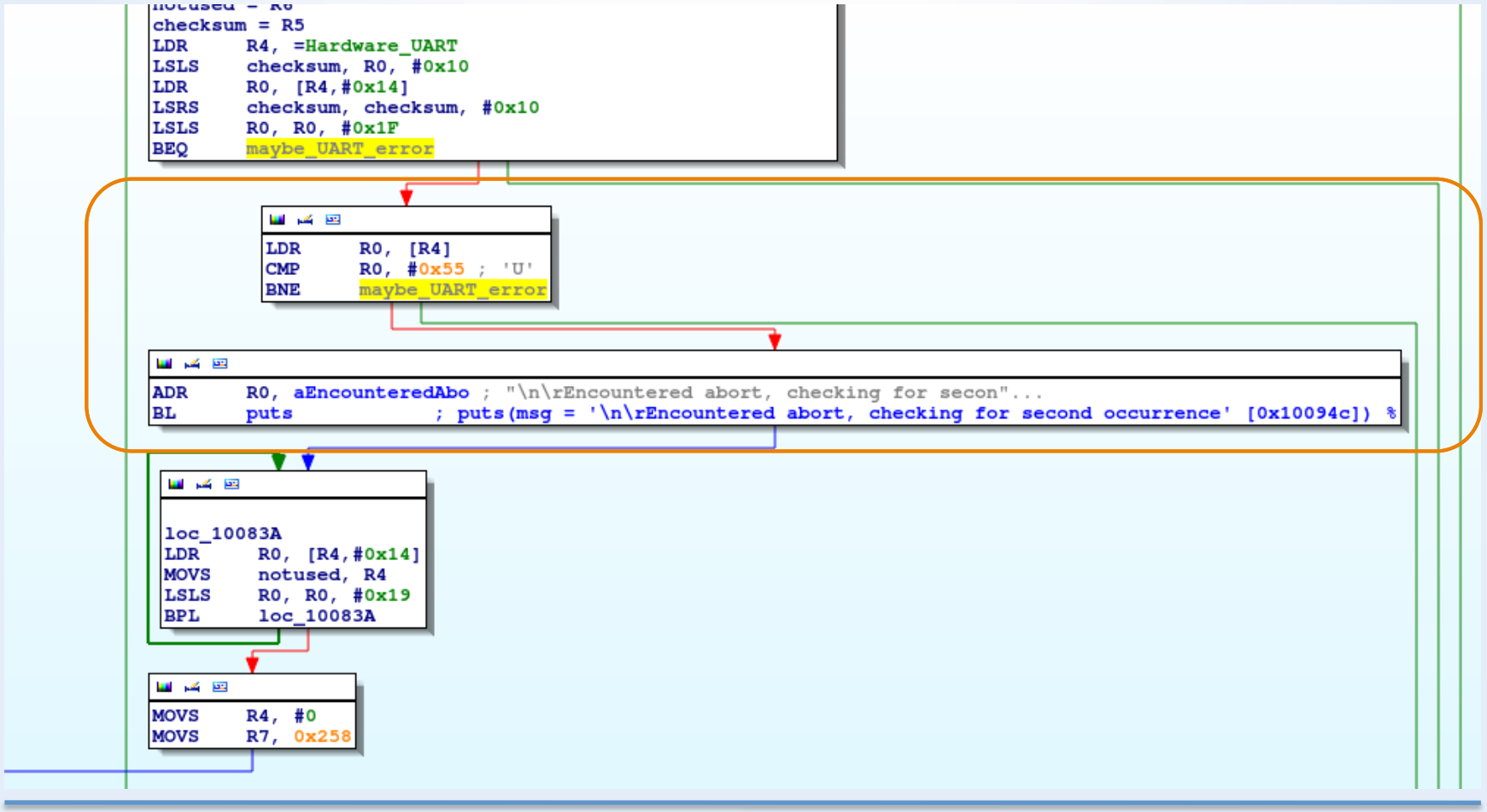
```
ASCII Diag mode

F3 T>
Spinning Down

Spin Down Complete
Elapsed Time 6.012 secs
Delaying 5000 msec

Jumping to Power On Reset
SEA-3 Yeti Boot ROM 2.0
  (12/06/2007)
Copyright Seagate  2007
```

```
Boot Cmds:
 DS
 AP <addr>
 WT <data>
 RD
 GO
 TE
 BR <divisor>
 BT
 WW
?
 RET
>
```

Inject a debugger

- Now we have poke (AP + WT) and execute (AP + GO)!
- This allows us to load and execute code on the drive's ARM processor
- The addresses of the *getc* and *putc* functions are known from the firmware disassembly
- I developed a tiny GDB stub (2.6k) that communicates with my host over UART and allows me to debug code on the drive

Accelerating the stub loading



Reconaissance

- Get ARM Coprocessor registers → CPUID, Memory protection settings, cache settings, etc.
- Drive still crashes when an invalid address is accessed → Reconstruct the memory map
  - Some regions are already known from the memory dump in the diagnostic menu
  - IO region is known from the serial port

Memory Map

Memory Range	Type
0x00000000 – 0x00008000	Code SRAM
0x00100000 – 0x00120000	ROM
0x00200000 – 0x00400000	Code DRAM
0x04000000 – 0x04004000	Data SRAM
0x40000000 – 0x50000000	IO
0x60000000 – 0x70000000	Data DRAM

Dumping the Flash

- Identify the flash read function in IDA
- Break execution at beginning of Flash read function
- Modify the parameters to read the part of the Flash that is interesting
- Dump the memory where the Flash data was read to with the GDB “dump binary … “ command

Following the execution

- Keeping control is challenging
- After loading the firmware from Flash to DRAM, this memory range is marked as read-only, breaking SW breakpoints → Overwrite the write-protect instruction with NOP
- Loading of the OS overwrites exception vector table, removing our debug exception handler → Watch flash loads and block the one writing to address 0x0

Following the execution (2)

- OS uses the whole code SRAM where the GDB stub resides → Move GDB stub to free DRAM memory after DRAM has been initialized and before SRAM is overwritten
- Execution "escapes" the debugger → Put a breakpoint in the UART interrupt handler, so that a CTRL+C will trigger the breakpoint

Dissecting the realtime OS

- The OS is custom kernel
  - Fixed number of tasks
  - Preemptive
  - Event-based: Each task has an accepted events mask, tasks can wait for a specific event or yield with generating an event to other tasks

Tasks in the bootloader FW

- Interrupt handler: Handles all hardware interrupts
- Read/write task: Handles accesses to the magnetic platters
- SATA task: Parses SATA requests and sends responses
- Diagnostic task?
- Load main firmware task?

But wait …

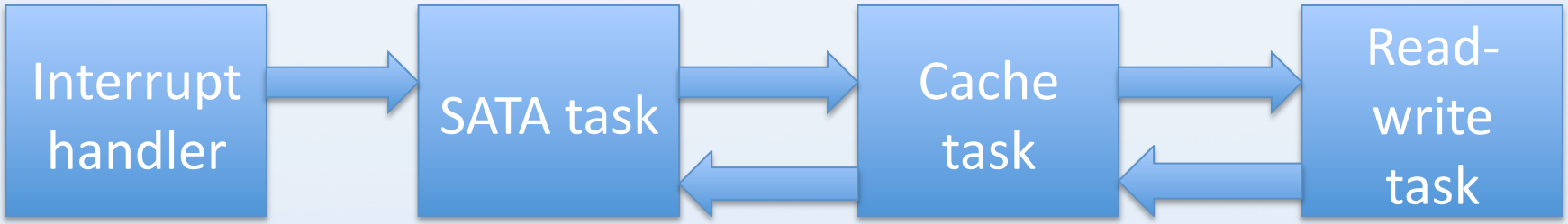
- Why did you say “Bootloader FW”?
- Well, actually the firmware from Flash serves only to load the actual firmware from the disk
- A very small unpacker stub then distributes this firmware in memory and runs it
- The main firmware is based on the same OS as the bootloader firmware

Tasks in the main FW

- Interrupt handler
- Read/write task
- Diagnostic task
- SATA task
- Cache manager task
- ??? task
- Power management task

Data flow for a SATA request

- Problems
  - Initial SATA packet written to memory by HW
  - All data is kept in global variables, dataflow is hard to trace …



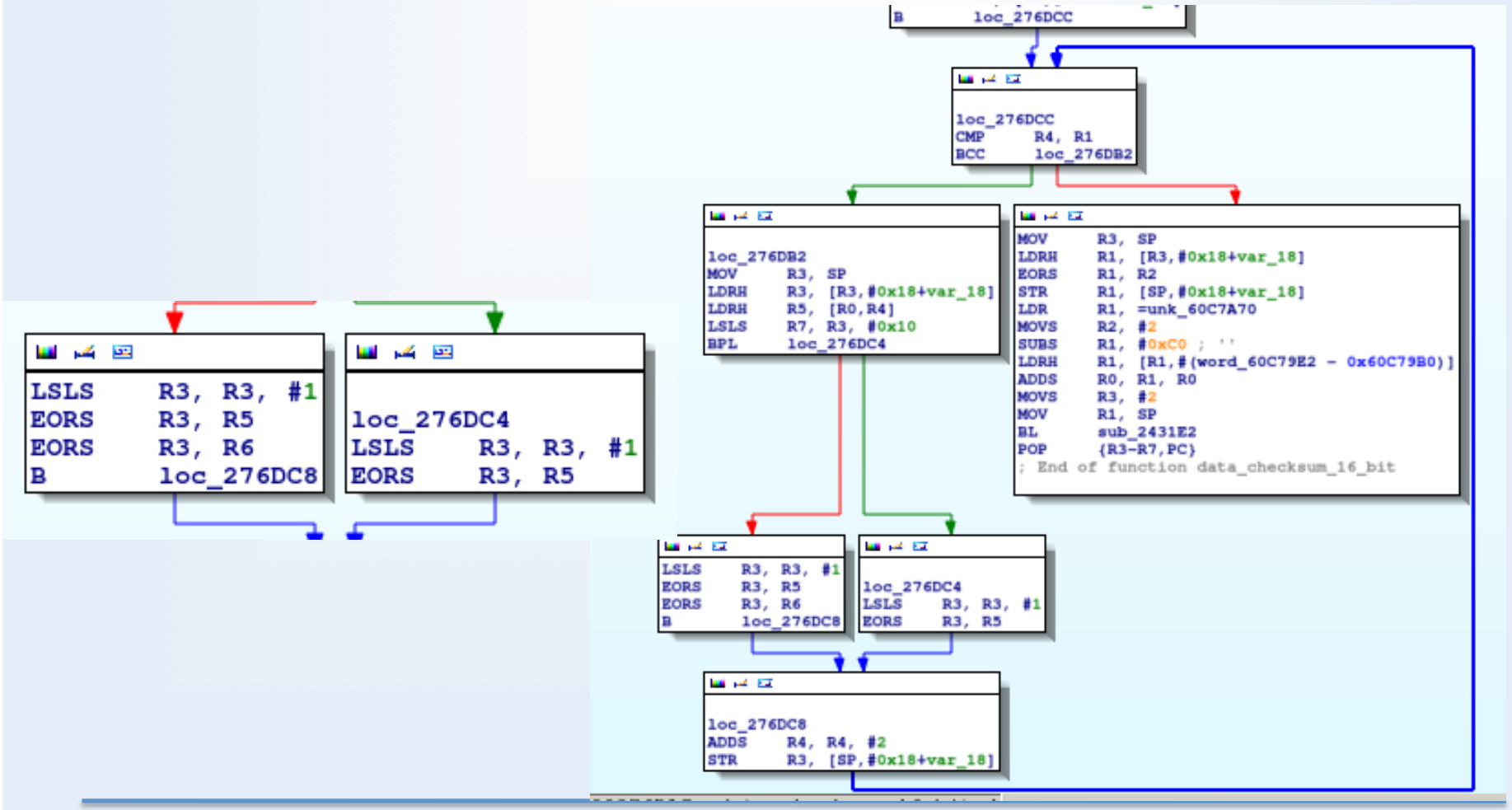
Tapping into the data flow

- Basically you can change data anywhere on its way to the R/W task
- I chose to intercept the flow in the cache task
  - This is where I first found a data structure pointing to the packet
  - Modifying the packet data would give us a full-blown backdoor …

Checksums

- Unfortunately, the drive raises an error and crashes when data is modified
- Observing the data in memory closely shows that each 512-byte packet is followed by 6 addional bytes
  - One 16-bit checksum
  - One 32-bit checksum
- After trying to figure the algorithm out for 2 days, I found it in the code …

Checksums (2)


B loc_276DCC
loc_276DCC
CMP R4, R1
BCC loc_276DB2
loc_276DB2
MOV R3, SP
LDRH R3, [R3,#0x18+var_18]
LDRH R5, [R0,R4]
LSLS R7, R3, #0x10
BPL loc_276DC4
MOV R3, SP
LDRH R1, [R3,#0x18+var_18]
EORS R1, R2
STR R1, [SP,#0x18+var_18]
LDR R1, =unk_60C7A70
MOVS R2, #2
SUBS R1, #0xC0 ; ''
LDRH R1, [R1,#(word_60C79E2 - 0x60C79B0)]
ADDS R0, R1, R0
MOVS R3, #2
MOV R1, SP
BL sub_2431E2
POP {R3-R7,PC}
; End of function data_checksum_16_bit
LSLS R3, R3, #1
EORS R3, R5
EORS R3, R6
B loc_276DC8
loc_276DC4
LSLS R3, R3, #1
EORS R3, R5
LSLS R3, R3, #1
EORS R3, R5
EORS R3, R6
B loc_276DC8
loc_276DC4
LSLS R3, R3, #1
EORS R3, R5
loc_276DC8
ADDS R4, R4, #2
STR R3, [SP,#0x18+var_18]

Roll your own backdoor

- Now we have all components for a backdoor
  - Wait for a magic packet (written to LBA x) that tells you which packet (at LBA y) to exfiltrate
  - Read that packet from LBA y, fix the checksums, and write it to LBA x
  - When LBA x is read again, a copy of the data at LBA y is retrieved

Distribute your FW

- Currently Seagate firmwares are updated through a DOS utility
- Hdparm also has a firmware update functionality, but it did not work for my drive
- The DOS utility could easily be embedded into the system start to flash the HDD once the computer is rebooted

Detection

- A modified FW is almost impossible to detect (except if you trigger the malicious behaviour)
- A modified FW can pretend to do a firmware upgrade while not doing one to protect itself
- Once written to the Flash, the firmware can burn a fuse of the Flash chip and make it read-only
- Only secure detection is through extraction and comparison

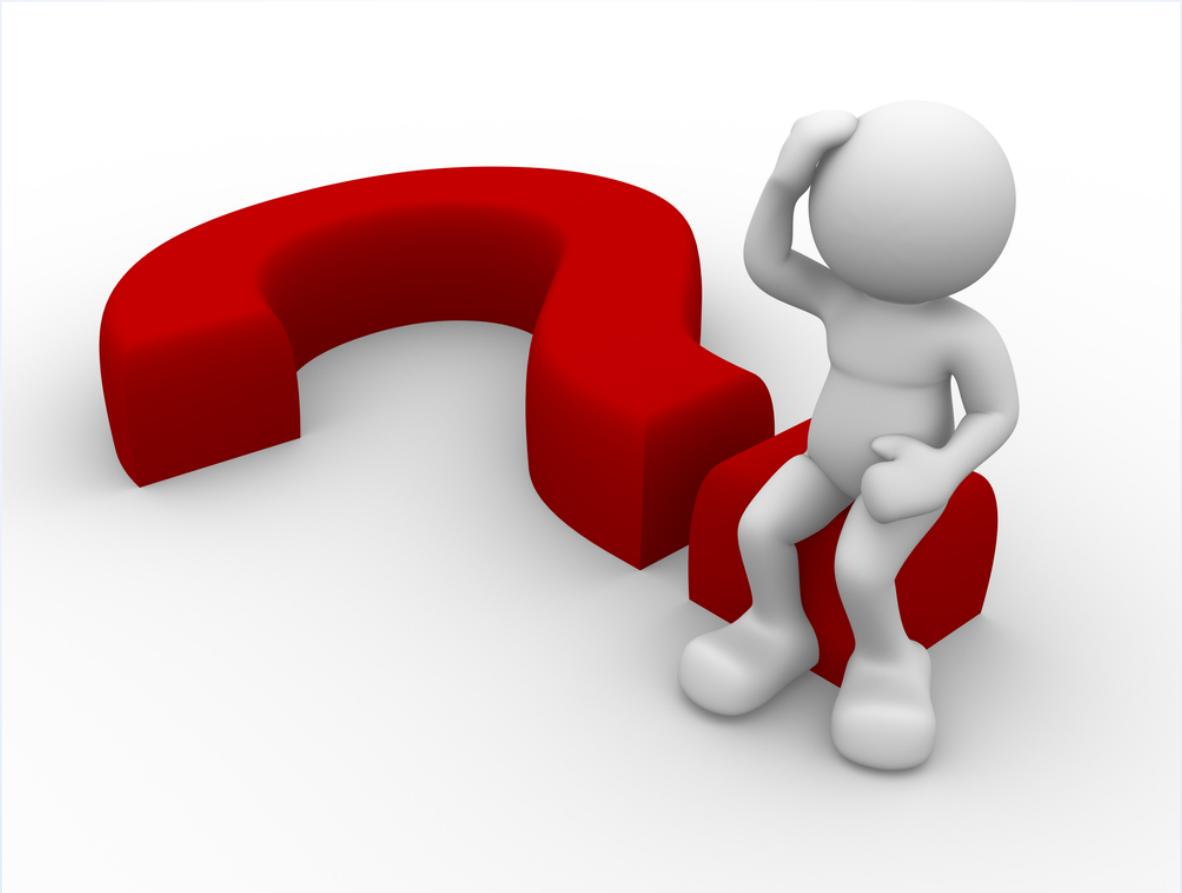
Countermeasures

- Sign that FW and only accept signed FWs!
- Do not allow code injection in the bootloader
- Does not help against bugs that allow code injection …
- Do not leave anybody with root privileges near your hard drive

Demo

It’s demo time!!!!

Questions



References

- [1] http://www.eurecom.fr
- [2] http://www.s3.eurecom.fr/~zaddach/index.html
- [3] http://spritesmods.com/?art=hddhack&page=1
- [4] http://forum.hddguru.com
- [5] http://www.s3.eurecom.fr/docs/acsac13_zaddach.pdf

GDB Stub

- GDB can connect to targets using a serial interface and a simple protocol
- There is a stub implementation in the source code tree, but not for ARM and it's bloated (for my purpose)
- 6 primitives are enough to give debugging support with software breakpoints:

  Read bytes, write bytes, read registers, write registers, continue and get signal

Diagnostic Overlays

- The firmware supports overlays, which is a means for OEMs to include custom functionality
- Overlays can hook into control flow and add functionality
- An overlay for diagnostics is provided with the original firmware
- The overlay is loaded once its functionality is needed

Reversing the firmware file format

- Try to find flash dump and memory dumps in a firmware update file → Bingo!
- File is organized in sections, each section containing
  - First stage bootloader
  - Flash image
  - Main firmware
  - Overlays
- If you are interested, write me for my hackish script