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| Lesson 10 Input01  Welcome to the Input lesson series. In this series, you will learn how to receive inputs to the Raspberry Pi using the keyboard. We will start with just revealing the input, and then move to a more traditional text prompt.  This first input lesson teaches some theory about drivers and linking, as well as about keyboards and ends up displaying text on the screen.   |  | | --- | | **Contents**   * [1 Getting Started](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/input01.html#gs) * [2 USB](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/input01.html#usb) * [3 Linking](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/input01.html#linking) * [4 Keyboards](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/input01.html#keyboards) * [5 The Nut Behind the Wheel](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/input01.html#driver) * [6 Updates Available](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/input01.html#ua) * [7 Look Up Tables](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/input01.html#lut) * [8 Notepad OS](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/input01.html#notepad) |   1 Getting Started  It is expected that you have completed the OK series, and it would be helpful to have completed the Screen series. Many of the files from that series will be called, without comment. If you do not have these files, or prefer to use a correct implementation, download the template for this lesson from the [Downloads](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/downloads.html) page. If you're using your own implementation, please remove everything after your call to SetGraphicsAddress.  2 USB  The USB standard was designed to make simple hardware in exchange for complex software.  As you are no doubt aware, the Raspberry Pi model B has two USB ports, commonly used for connecting a mouse and keyboard. This was a very good design decision, USB is a very generic connector, and many different kinds of device use it. It's simple to build new devices for, simple to write device drivers for, and is highly extensible thanks to USB hubs. Could it get any better? Well, no, in fact for an Operating Systems developer this is our worst nightmare. The USB standard is huge. I really mean it this time, it is over 700 pages, before you've even thought about connecting a device.  I spoke to a number of other hobbyist Operating Systems developers about this and they all say one thing: don't bother. "It will take too long to implement", "You won't be able to write a tutorial on it" and "It will be of little benefit". In many ways they are right, I'm not able to write a tutorial on the USB standard, as it would take weeks. I also can't teach how to write device drivers for all the different devices, so it is useless on its own. However, I can do the next best thing: Get a working USB driver, get a keyboard driver, and then teach how to use these in an Operating System. I set out searching for a free driver that would run in an operating system that doesn't even know what a file is yet, but I couldn't find one. They were all too high level. So, I attempted to write one. Everybody was right, this took weeks to do. However, I'm pleased to say I did get one that works with no external help from the Operating System, and can talk to a mouse and keyboard. It is by no means complete, efficient, or correct, but it does work. It has been written in C and the full source code can be found on the downloads page for those interested.  So, this tutorial won't be a lesson on the USB standard (at all). Instead we'll look at how to work with other people's code.  3 Linking  Linking allows us to make reusable code 'libraries' that anyone can use in their program.  Since we're about to incorporate external code into the Operating System, we need to talk about linking. Linking is a process which is applied to programs or Operating System to link in functions. What this means is that when a program is made, we don't necessarily code every function (almost certainly not in fact). Linking is what we do to make our program link to functions in other people's code. This has actually been going on all along in our Operating Systems, as the linker links together all of the different files, each of which is compiled separately.  Programs often just call libraries, which call other libraries and so on until eventually they call an Operating System library which we would write.  There are two types of linking: static and dynamic. Static linking is like what goes on when we make our Operating Systems. The linker finds all the addresses of the functions, and writes them into the code, before the program is finished. Dynamic linking is linking that occurs after the program is 'complete'. When it is loaded, the dynamic linker goes through the program and links any functions which are not in the program to libraries in the Operating System. This is one of the jobs our Operating System should eventually be capable of, but for now everything will be statically linked.  The USB driver I have written is suitable for static linking. This means I give you the compiled code for each of my files, and then the linker finds functions in your code which are not defined in your code, and links them to functions in my code. On the [Downloads](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/downloads.html) page for this lesson is a makefile and my USB driver, which you will need to continue. Download them and replace the makefile in your code with this one, and also put the driver in the same folder as that makefile.  4 Keyboards  In order to get input into our Operating System, we need to understand at some level how keyboards actually work. Keyboards have two types of keys: Normal and Modifier keys. The normal keys are the letters, numbers, function keys, etc. They constitute almost every key on the keyboard. The modifiers are up to 8 special keys. These are left shift, right shift, left control, right control, left alt, right alt, left GUI and right GUI. The keyboard can detect any combination of the modifier keys being held, as well as up to 6 normal keys. Every time a key changes (i.e. is pushed or released), it reports this to the computer. Typically, keyboards also have three LEDs for Caps Lock, Num Lock and Scroll Lock, which are controlled by the computer, not the keyboard itself. Keyboards may have many more lights such as power, mute, etc.  In order to help standardise USB keyboards, a table of values was produced, such that every keyboard key ever is given a unique number, as well as every conceivable LED. The table below lists the first 126 of values.   | Table 4.1 USB Keyboard Keys | | | | | | | | | --- | --- | --- | --- | --- | --- | --- | --- | | **Number** | **Description** | **Number** | **Description** | **Number** | **Description** | **Number** | **Description** | | 4 | a and A | 5 | b and B | 6 | c and C | 7 | d and D | | 8 | e and E | 9 | f and F | 10 | g and G | 11 | h and H | | 12 | i and I | 13 | j and J | 14 | k and K | 15 | l and L | | 16 | m and M | 17 | n and N | 18 | o and O | 19 | p and P | | 20 | q and Q | 21 | r and R | 22 | s and S | 23 | t and T | | 24 | u and U | 25 | v and V | 26 | w and W | 27 | x and X | | 28 | y and Y | 29 | z and Z | 30 | 1 and ! | 31 | 2 and @ | | 32 | 3 and # | 33 | 4 and $ | 34 | 5 and % | 35 | 6 and ^ | | 36 | 7 and & | 37 | 8 and \* | 38 | 9 and ( | 39 | 0 and ) | | 40 | Return (Enter) | 41 | Escape | 42 | Delete (Backspace) | 43 | Tab | | 44 | Spacebar | 45 | - and \_ | 46 | = and + | 47 | [ and { | | 48 | ] and } | 49 | \ and | | 50 | # and ~ | 51 | ; and : | | 52 | ' and " | 53 | ` and ~ | 54 | , and < | 55 | . and > | | 56 | / and ? | 57 | Caps Lock | 58 | F1 | 59 | F2 | | 60 | F3 | 61 | F4 | 62 | F5 | 63 | F6 | | 64 | F7 | 65 | F8 | 66 | F9 | 67 | F10 | | 68 | F11 | 69 | F12 | 70 | Print Screen | 71 | Scroll Lock | | 72 | Pause | 73 | Insert | 74 | Home | 75 | Page Up | | 76 | Delete forward | 77 | End | 78 | Page Down | 79 | Right Arrow | | 80 | Left Arrow | 81 | Down Arrow | 82 | Up Arrow | 83 | Num Lock | | 84 | Keypad / | 85 | Keypad \* | 86 | Keypad - | 87 | Keypad + | | 88 | Keypad Enter | 89 | Keypad 1 and End | 90 | Keypad 2 and Down Arrow | 91 | Keypad 3 and Page Down | | 92 | Keypad 4 and Left Arrow | 93 | Keypad 5 | 94 | Keypad 6 and Right Arrow | 95 | Keypad 7 and Home | | 96 | Keypad 8 and Up Arrow | 97 | Keypad 9 and Page Up | 98 | Keypad 0 and Insert | 99 | Keypad . and Delete | | 100 | \ and | | 101 | Application | 102 | Power | 103 | Keypad = | | 104 | F13 | 105 | F14 | 106 | F15 | 107 | F16 | | 108 | F17 | 109 | F18 | 110 | F19 | 111 | F20 | | 112 | F21 | 113 | F22 | 114 | F23 | 115 | F24 | | 116 | Execute | 117 | Help | 118 | Menu | 119 | Select | | 120 | Stop | 121 | Again | 122 | Undo | 123 | Cut | | 124 | Copy | 125 | Paste | 126 | Find | 127 | Mute | | 128 | Volume Up | 129 | Volume Down |  |  |  |  |   The full list can be found in section 10, page 53 of [HID Usage Tables 1.12](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/downloads/hut1_12v2.pdf).  5 The Nut Behind the Wheel  These summaries and the code they describe form an API - Application Product Interface.  Normally, when you work with someone else's code, they provide a summary of their methods, what they do and roughly how they work, as well as how they can go wrong. Here is a table of the relevant instructions required to use my USB driver.   | Table 5.1 Keyboard related functions in CSUD | | | | | --- | --- | --- | --- | | **Function** | **Arguments** | **Returns** | **Description** | | UsbInitialise | None | r0 is result code | This method is the all-in-one method that loads the USB driver, enumerates all devices and attempts to communicate with them. This method generally takes about a second to execute, though with a few USB hubs plugged in this can be significantly longer. After this method is completed methods in the keyboard driver become available, regardless of whether or not a keyboard is indeed inserted. Result code explained below. | | UsbCheckForChange | None | None | Essentially provides the same effect as UsbInitialise, but does not provide the same one time initialisation. This method checks every port on every connected hub recursively, and adds new devices if they have been added. This should be very quick if there are no changes, but can take up to a few seconds if a hub with many devices is attached. | | KeyboardCount | None | r0 is count | Returns the number of keyboards currently connected and detected. UsbCheckForChange may update this. Up to 4 keyboards are supported by default. Up to this many keyboards may be accessed through this driver. | | KeyboardGetAddress | r0 is index | r0 is address | Retrieves the address of a given keyboard. All other functions take a keyboard address in order to know which keyboard to access. Thus, to communicate with a keyboard, first check the count, then retrieve the address, then use other methods. Note, the order of keyboards that this method returns may change after calls to UsbCheckForChange. | | KeyboardPoll | r0 is address | r0 is result code | Reads in the current key state from the keyboard. This operates via polling the device directly, contrary to the best practice. This means that if this method is not called frequently enough, a key press could be missed. All reading methods simply return the value as of the last poll. | | KeyboardGetModifiers | r0 is address | r0 is modifier state | Retrieves the status of the modifier keys as of the last poll. These are the shift, alt control and GUI keys on both sides. This is returned as a bit field, such that a 1 in the bit 0 means left control is held, bit 1 means left shift, bit 2 means left alt, bit 3 means left GUI and bits 4 to 7 mean the right versions of those previous. If there is a problem r0 contains 0. | | KeyboardGetKeyDownCount | r0 is address | r0 is count | Retrieves the number of keys currently held down on the keyboard. This excludes modifier keys. Normally, this cannot go above 6. If there is an error this method returns 0. | | KeyboardGetKeyDown | r0 is address, r1 is key number | r0 is scan code | Retrieves the scan code (see Table 4.1) of a particular held down key. Normally, to work out which keys are down, call KeyboardGetKeyDownCount and then call KeyboardGetKeyDown up to that many times with increasing values of r1 to determine which keys are down. Returns 0 if there is a problem. It is safe (but not recommended) to call this method without calling KeyboardGetKeyDownCount and interpret 0s as keys not held. Note, the order or scan codes can change randomly (some keyboards sort numerically, some sort temporally, no guarantees are made). | | KeyboardGetKeyIsDown | r0 is address, r1 is scan code | r0 is status | Alternative to KeyboardGetKeyDown, checks if a particular scan code is among the held down keys. Returns 0 if not, or a non-zero value if so. Faster when detecting particular scan codes (e.g. looking for ctrl+c). On error, returns 0. | | KeyboardGetLedSupport | r0 is address | r0 is LEDs | Checks which LEDs a particular keyboard supports. Bit 0 being 1 represents Number Lock, bit 1 represents Caps Lock, bit 2 represents Scroll Lock, bit 3 represents Compose, bit 4 represents Kana, bit 5 represents Power, bit 6 represents Mute and bit 7 represents Compose. As per the USB standard, none of these LEDs update automatically (e.g. Caps Lock must be set manually when the Caps Lock scan code is detected). | | KeyboardSetLeds | r0 is address, r1 is LEDs | r0 is result code | Attempts to turn on/off the specified LEDs on the keyboard. See below for result code values. See KeyboardGetLedSupport for LEDs' values. |   Result codes are an easy way to handle errors, but often more elegant solutions exist in higher level code.  Several methods return 'result codes'. These are commonplace in C code, and are just numbers which represent what happened in a method call. By convention, 0 always indicates success. The following result codes are used by this driver.   | Table 5.2 - CSUD Result Codes | | | --- | --- | | **Code** | **Description** | | 0 | Method completed successfully. | | -2 | Argument: A method was called with an invalid argument. | | -4 | Device: The device did not respond correctly to the request. | | -5 | Incompatible: The driver is not compatible with this request or device. | | -6 | Compiler: The driver was compiled incorrectly, and is broken. | | -7 | Memory: The driver ran out of memory. | | -8 | Timeout: The device did not respond in the expected time. | | -9 | Disconnect: The device requested has disconnected, and cannot be used. |   The general usage of the driver is as follows:   1. Call UsbInitialise 2. Call UsbCheckForChange 3. Call KeyboardCount 4. If this is 0, go to 2. 5. For each keyboard you support:    1. Call KeyboardGetAddress    2. Call KeybordGetKeyDownCount    3. For each key down:       1. Check whether or not it has just been pushed       2. Store that the key is down    4. For each key stored:       1. Check whether or not key is released       2. Remove key if released 6. Perform actions based on keys pushed/released 7. Go to 2.   Ultimately, you may do whatever you wish to with the keyboard, and these methods should allow you to access all of its functionality. Over the next 2 lessons, we shall look at completing the input side of a text terminal, similarly to most command line computers, and interpreting the commands. In order to do this, we're going to need to have keyboard inputs in a more useful form. You may notice that my driver is (deliberately) unhelpful, because it doesn't have methods to deduce whether or not a key has just been pushed down or released, it only has methods about what is currently held down. This means we'll need to write such methods ourselves.  6 Updates Available  Repeatedly checking for updates is called 'polling'. This is in contrast to interrupt driven IO, where the device sends a signal when data is ready.  First of all, let's implement a method KeyboardUpdate which detects the first keyboard and uses its poll method to get the current input, as well as saving the last inputs for comparison. We can then use this data with other methods to translate scan codes to keys. The method should do precisely the following:   1. Retrieve a stored keyboard address (initially 0). 2. If this is not 0, go to 9. 3. Call UsbCheckForChange to detect new keyboards. 4. Call KeyboardCount to detect how many keyboards are present. 5. If this is 0 store the address as 0 and return; we can't do anything with no keyboard. 6. Call KeyboardGetAddress with parameter 0 to get the first keyboard's address. 7. Store this address. 8. If this is 0, return; there is some problem. 9. Call KeyboardGetKeyDown 6 times to get each key currently down and store them 10. Call KeyboardPoll 11. If the result is non-zero go to 3. There is some problem (such as disconnected keyboard).   To store the values mentioned above, we will need the following values in the .data section.  .section .data .align 2 KeyboardAddress: .int 0 KeyboardOldDown: .rept 6 .hword 0 .endr  **.hword num** inserts the half word constant **num** into the file directly.  **.rept num [commands] .endr** copies the commands **commands** to the output **num** times.  Try to implement the method yourself. My implementation for this is as follows:   1. .section .text .globl KeyboardUpdate KeyboardUpdate: push {r4,r5,lr}  kbd .req r4 ldr r0,=KeyboardAddress ldr kbd,[r0]   We load in the keyboard address.   1. teq kbd,#0 bne haveKeyboard$   If the address is non-zero, we have a keyboard. Calling UsbCheckForChanges is slow, and so if everything works we avoid it.   1. getKeyboard$: bl UsbCheckForChange   If we don't have a keyboard, we have to check for new devices.   1. bl KeyboardCount   Now we see if a new keyboard has been added.   1. teq r0,#0 ldreq r1,=KeyboardAddress streq r0,[r1] beq return$   There are no keyboards, so we have no keyboard address.   1. mov r0,#0 bl KeyboardGetAddress   Let's just get the address of the first keyboard. You may want to allow more.   1. ldr r1,=KeyboardAddress str r0,[r1]   Store the keyboard's address.   1. teq r0,#0 beq return$ mov kbd,r0   If we have no address, there is nothing more to do.   1. saveKeys$:   mov r0,kbd mov r1,r5 bl KeyboardGetKeyDown  ldr r1,=KeyboardOldDown add r1,r5,lsl #1 strh r0,[r1] add r5,#1 cmp r5,#6 blt saveKeys$  Loop through all the keys, storing them in KeyboardOldDown. If we ask for too many, this returns 0 which is fine.   1. mov r0,kbd bl KeyboardPoll   Now we get the new keys.   1. teq r0,#0 bne getKeyboard$  return$: pop {r4,r5,pc} .unreq kbd   Finally we check if KeyboardPoll worked. If not, we probably disconnected.  With our new KeyboardUpdate method, checking for inputs becomes as simple as calling this method at regular intervals, and it will even check for disconnections etc. This is a useful method to have, as our actual key processing may differ based on the situation, and so being able to get the current input in its raw form with one method call is generally applicable. The next method we ideally want is KeyboardGetChar, a method that simply returns the next key pressed as an ASCII character, or returns 0 if no key has just been pressed. This could be extended to support typing a key multiple times if it is held for a certain duration, and to support the 'lock' keys as well as modifiers.  To make this method it is useful if we have a method KeyWasDown, which simply returns 0 if a given scan code is not in the KeyboardOldDown values, and returns a non-zero value otherwise. Have a go at implementing this yourself. As always, a solution can be found on the downloads page.  7 Look Up Tables  In many areas of programming, the larger the program, the faster it is. Look up tables are large, but are very fast. Some problems can be solved by a mixture of look up tables and normal functions.  The KeyboardGetChar method could be quite complex if we write it poorly. There are 100s of scan codes, each with different effects depending on the presence or absence of the shift key or other modifiers. Not all of the keys can be translated to a character. For some characters, multiple keys can produce the same character. A useful trick in situations with such vast arrays of possibilities is look up tables. A look up table, much like in the physical sense, is a table of values and their results. For some limited functions, the simplest way to deduce the answer is just to precompute every answer, and just return the correct one by retrieving it. In this case, we could build up a sequence of values in memory such that the nth value into the sequence is the ASCII character code for the scan code n. This means our method would simply have to detect if a key was pressed, and then retrieve its value from the table. Further, we could have a separate table for the values when shift is held, so that the shift key simply changes which table we're working with.  After the **.section .data** command, copy the following tables:  .align 3 KeysNormal:  .byte 0x0, 0x0, 0x0, 0x0, 'a', 'b', 'c', 'd' .byte 'e', 'f', 'g', 'h', 'i', 'j', 'k', 'l' .byte 'm', 'n', 'o', 'p', 'q', 'r', 's', 't' .byte 'u', 'v', 'w', 'x', 'y', 'z', '1', '2' .byte '3', '4', '5', '6', '7', '8', '9', '0' .byte '\n', 0x0, '\b', '\t', ' ', '-', '=', '[' .byte ']', '\\', '#', ';', '\'', '`', ',', '.' .byte '/', 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, '/', '\*', '-', '+' .byte '\n', '1', '2', '3', '4', '5', '6', '7' .byte '8', '9', '0', '.', '\\', 0x0, 0x0, '='  .align 3 KeysShift:  .byte 0x0, 0x0, 0x0, 0x0, 'A', 'B', 'C', 'D' .byte 'E', 'F', 'G', 'H', 'I', 'J', 'K', 'L' .byte 'M', 'N', 'O', 'P', 'Q', 'R', 'S', 'T' .byte 'U', 'V', 'W', 'X', 'Y', 'Z', '!', '"' .byte '£', '$', '%', '^', '&', '\*', '(', ')' .byte '\n', 0x0, '\b', '\t', ' ', '\_', '+', '{' .byte '}', '|', '~', ':', '@', '¬', '<', '>' .byte '?', 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, '/', '\*', '-', '+' .byte '\n', '1', '2', '3', '4', '5', '6', '7' .byte '8', '9', '0', '.', '|', 0x0, 0x0, '='  **.byte num** inserts the byte constant **num** into the file directly.  Most assemblers and compilers recognise escape sequences; character sequences such as \t which insert special characters instead.  These tables map directly the first 104 scan codes onto the ASCII characters as a table of bytes. We also have a separate table describing the effects of the shift key on those scan codes. I've used the ASCII null character (0) for all keys without direct mappings in ASCII (such as the function keys). Backspace is mapped to the ASCII backspace character (8 denoted \b), enter is mapped to the ASCII new line character (10 denoted \n) and tab is mapped to the ASCII horizontal tab character (9 denoted \t).  The KeyboardGetChar method will need to do the following:   1. Check if KeyboardAddress is 0. If so, return 0. 2. Call KeyboardGetKeyDown up to 6 times. Each time:    1. If key is 0, exit loop.    2. Call KeyWasDown. If it was, go to the next key.    3. If the scan code is more than 103, go to the next key.    4. Call KeyboardGetModifiers    5. If shift is held, load the address of KeysShift. Otherwise load KeysNormal.    6. Read the ASCII value from the table.    7. If it is 0, go to the next key otherwise return this ASCII code and exit. 3. Return 0.   Try to implement this yourself. My implementation is presented below:   1. .globl KeyboardGetChar KeyboardGetChar: ldr r0,=KeyboardAddress ldr r1,[r0] teq r1,#0 moveq r0,#0 moveq pc,lr   Simple check to see if we have a keyboard.   1. push {r4,r5,r6,lr} kbd .req r4 key .req r6 mov r4,r1 mov r5,#0 keyLoop$:   mov r0,kbd mov r1,r5 bl KeyboardGetKeyDown  r5 will hold the index of the key, r4 holds the keyboard address.   * 1. teq r0,#0 beq keyLoopBreak$   If a scan code is 0, it either means there is an error, or there are no more keys.   * 1. mov key,r0 bl KeyWasDown teq r0,#0 bne keyLoopContinue$   If a key was already down it is uninteresting, we only want ot know about key presses.   * 1. cmp key,#104 bge keyLoopContinue$   If a key has a scan code higher than 104, it will be outside our table, and so is not relevant.   * 1. mov r0,kbd bl KeyboardGetModifiers   We need to know about the modifier keys in order to deduce the character.   * 1. tst r0,#0b00100010 ldreq r0,=KeysNormal ldrne r0,=KeysShift   We detect both a left and right shift key as changing the characters to their shift variants. Remember, a **tst** instruction computes the logical AND and then compares it to zero, so it will be equal to 0 if and only if both of the shift bits are zero.   * 1. ldrb r0,[r0,key]   Now we can load in the key from the look up table.   * 1. teq r0,#0 bne keyboardGetCharReturn$ keyLoopContinue$: add r5,#1 cmp r5,#6 blt keyLoop$   If the look up code contains a zero, we must continue. To continue, we increment the index, and check if we've reached 6.   1. keyLoopBreak$: mov r0,#0 keyboardGetCharReturn$: pop {r4,r5,r6,pc} .unreq kbd .unreq key   We return our key here, if we reach keyLoopBreak$, then we know there is no key held, so return 0.  8 Notepad OS  Now we have our KeyboardGetChar method, we can make an operating system that just types what the user writes to the screen. For simplicity we'll ignore all the unusual keys. In 'main.s' delete all code after **bl SetGraphicsAddress**. Call UsbInitialise, set r4 and r5 to 0, then loop forever over the following commands:   1. Call KeyboardUpdate 2. Call KeyboardGetChar 3. If it is 0, got to 1 4. Copy r4 and r5 to r1 and r2 then call DrawCharacter 5. Add r0 to r4 6. If r4 is 1024, add r1 to r5 and set r4 to 0 7. If r5 is 768 set r5 to 0 8. Go to 1   Now compile this and test it on the Pi. You should almost immediately be able to start typing text to the screen when the Pi starts. If not, please see our troubleshooting page.  When it works, congratulations, you've achieved an interface with the computer. You should now begin to realise that you've almost got a primitive operating system together. You can now interface with the computer, issuing it commands, and receive feedback on screen. In the next tutorial, [Input02](http://www.cl.cam.ac.uk/projects/raspberrypi/tutorials/os/input02.html) we will look at producing a full text terminal, in which the user types commands, and the computer executes them. | 第十课 输入01  欢迎来到输入系列课程。在这个系列中，你将会学习到如何在树莓派上利用键盘来接受数据。我们将以展示输入位开始，然后转向到一个更加传统的字符提示符。  输入课程的第一课将教与驱动和链接有关的一些理论，同时也教授键盘和在屏幕上显示文本的终端。  目录  1. 开始  2. USB  3. 链接  4. 键盘  5. 底层细节  6. 更新可用  7. 查表  8. 记事板操作系统  1. 开始  我们预计你已经完成了OK系列课程的学习。如果你已经完成了屏幕课程的学习，那么对你的帮助也是很大的。之前系列课程的用到的或者编写的文件，有许多会被用到，这里不再评论。如果你还没有之前提到的那些文件，或者你想使用一个正确实现的版本，那你可以从下载页上下载本课程的模板。如果你要使用你自己的实现文件，请把调用函数SetGraphicsAddress之后的所有代码全部清除掉。  2. USB  USB标准设计的初衷是为了满足复杂软件之间通过简单的硬件来交互信息的需求。  正如大家心知肚明的一样，树莓派B版有两个USB口，一般情况下是用来连接鼠标和键盘的。这是一个非常棒的设计决策。USB是一种非常普通的连接器，有许多种设备使用它。不仅创建设备非常容易，往设备里写入数据也很简单，而且基于USB集线器，扩展也很方便。还能更好吗？好吧。实际上这对操作系统开发者来说是个噩梦。USB标准非常庞大。在你可以连接一个设备之前，你就要阅读将近700页的文本。  我和许多业余操作系统开发者讨论过此事，他们总是讲一件事：不用烦恼。“它太长了，无法实现。”，“你不可能写出一个关于 它的教程。”和“几乎不可能受益。”在许多方面他们都正确的。我不可能写一个关于USB标准的教程，因为这将花费数周时间。我也无法教授如何写出所有不同种类设备的驱动程序，所以它本身并没有什么用处。经管如此，下一步可以做的最好的是：拿一个USB驱动和键盘驱动过来，然后教授如何在一个操作系统中使用这些驱动。我准备寻找一个自由免费的驱动，我并不需要知道其文件里到底是什么。但是，这样的驱动找不到。它们的层次太高。那么，我尝试着自己写一个。所有人都是正确的，这项工作的确需要数周的时间。我可以很高兴地在这里告诉大家，我的确写出了一个不需要操作系统额外帮助的驱动。这个驱动可以和鼠标和键盘进行交流沟通。不过这项工作还没有彻底、有效亦或正确地完成，不过它还是可以工作的。这个驱动使用C语言写成，而且它的源代码可以从下载页上面获得。  那么，这个教程并不是关于USB标准的课程。取而代之的是，我们将要学习如何和其他人的代码一起协作。  3. 链接  链接允许我们可以让一个称为“库文件”的一堆代码得到重用。  因为我们将要把其他额外的代码并入到操作系统中去，所以我们需要讨论一下链接。链接是一个被程序或者操作系统使用的进程，用于链接函数。这就意味着当我们想要编写一个函数时，我们并不需要编写每一个函数（实际上也完全没有必要）。链接要做的就是把我们编写的程序中的函数链接到其他人的代码上。这种方法将会在我们的操作系统中持续使用。连接器会把所有不同的文件链接起来，而每一个被链接的文件都是独立的。  程序常常需要调用库，这些库也通常会调用到其他的库。这样的循环只到调用到我们所写的操作系统库函数为止。  有两种类型的链接：静态的和动态的。静态链接类似于我们制作操作系统的过程。链接器会寻找所有函数的地址，然后它这些地址写入到代码中。这个写入操作是在程序被制作成型之前完成的。动态链接发生在程序制作完成之后发生的。当动态链接库被加载时，动态链接器会先通读一遍程序，把其中任何没有链接到库的函数统统链接到在操作系统中的库上。这将是我们编写的操作系统需要提供的功能。但是现在，所有的事情都是将是静态的。  我编写的USB驱动程序很适合于静态链接。这意味着我会把我每个文件已经编译过的代码给你，然后链接器会在你的代码中寻找还没有定义的函数，并把他们链接到我的代码中去。在这一课的下载页中，有我的USB驱动程序和一个makefile文件，可能你会用到。把这个makefile文件下载下来，并把它取代你代码文件中的那个，然后把驱动程序放置在和makefile文件相同的目录下。   1. 键盘   为了给我们的操作系统一些输入，我们需要在操作系统的级别理解键盘是如何工作的。键盘有两类按键：普通按键和辅助按键。普通按键包括字母，数字，功能按键等。他们几乎构成了整个键盘上的所有按键的组合。辅助按键包括8个键。他们分别是左shift, 右shift, 左control, 右control, 左alt, 右alt, 左GUI and 右GUI键。键盘能够探测到当辅助按键和普通按键的任何组合，这个组合包括一个普通按键和任意不多于6个普通按键。每当一个按键的状态发生了改变（比如被按下或者被释放），键盘都会向计算机进行报告。经典的键盘还包括三个LED提示灯，它们分别是大写锁定，数字键盘锁定以及滚屏锁定。这三个灯分别是由计算机来控制的，而不是键盘本身。键盘可以安置更多的提示灯，比如电源灯或音量灯等等。  为了辅助标准化USB键盘，一个键值表被制作了出来。其中每一个按键都给出了一个独一无二的数值，其中包括了可能出现的LED灯。下表列出了头126个数值。   | Table 4.1 USB Keyboard Keys | | | | | | | | | --- | --- | --- | --- | --- | --- | --- | --- | | **Number** | **Description** | **Number** | **Description** | **Number** | **Description** | **Number** | **Description** | | 4 | a and A | 5 | b and B | 6 | c and C | 7 | d and D | | 8 | e and E | 9 | f and F | 10 | g and G | 11 | h and H | | 12 | i and I | 13 | j and J | 14 | k and K | 15 | l and L | | 16 | m and M | 17 | n and N | 18 | o and O | 19 | p and P | | 20 | q and Q | 21 | r and R | 22 | s and S | 23 | t and T | | 24 | u and U | 25 | v and V | 26 | w and W | 27 | x and X | | 28 | y and Y | 29 | z and Z | 30 | 1 and ! | 31 | 2 and @ | | 32 | 3 and # | 33 | 4 and $ | 34 | 5 and % | 35 | 6 and ^ | | 36 | 7 and & | 37 | 8 and \* | 38 | 9 and ( | 39 | 0 and ) | | 40 | Return (Enter) | 41 | Escape | 42 | Delete (Backspace) | 43 | Tab | | 44 | Spacebar | 45 | - and \_ | 46 | = and + | 47 | [ and { | | 48 | ] and } | 49 | \ and | | 50 | # and ~ | 51 | ; and : | | 52 | ' and " | 53 | ` and ~ | 54 | , and < | 55 | . and > | | 56 | / and ? | 57 | Caps Lock | 58 | F1 | 59 | F2 | | 60 | F3 | 61 | F4 | 62 | F5 | 63 | F6 | | 64 | F7 | 65 | F8 | 66 | F9 | 67 | F10 | | 68 | F11 | 69 | F12 | 70 | Print Screen | 71 | Scroll Lock | | 72 | Pause | 73 | Insert | 74 | Home | 75 | Page Up | | 76 | Delete forward | 77 | End | 78 | Page Down | 79 | Right Arrow | | 80 | Left Arrow | 81 | Down Arrow | 82 | Up Arrow | 83 | Num Lock | | 84 | Keypad / | 85 | Keypad \* | 86 | Keypad - | 87 | Keypad + | | 88 | Keypad Enter | 89 | Keypad 1 and End | 90 | Keypad 2 and Down Arrow | 91 | Keypad 3 and Page Down | | 92 | Keypad 4 and Left Arrow | 93 | Keypad 5 | 94 | Keypad 6 and Right Arrow | 95 | Keypad 7 and Home | | 96 | Keypad 8 and Up Arrow | 97 | Keypad 9 and Page Up | 98 | Keypad 0 and Insert | 99 | Keypad . and Delete | | 100 | \ and | | 101 | Application | 102 | Power | 103 | Keypad = | | 104 | F13 | 105 | F14 | 106 | F15 | 107 | F16 | | 108 | F17 | 109 | F18 | 110 | F19 | 111 | F20 | | 112 | F21 | 113 | F22 | 114 | F23 | 115 | F24 | | 116 | Execute | 117 | Help | 118 | Menu | 119 | Select | | 120 | Stop | 121 | Again | 122 | Undo | 123 | Cut | | 124 | Copy | 125 | Paste | 126 | Find | 127 | Mute | | 128 | Volume Up | 129 | Volume Down |  |  |  |  |   完整的清单可以在这个pdf文档第53页的第10节中找到。   1. 底层细节   这些代码以及描述他们的概要构成了API（应用程序接口）。  一般情况下，当你和别人的代码协同工作时，他们提供他们工作的一个概要型描述。通常包括这些代码可以做什么以及简单地描述它们是如何工作的，其中当然包括它们在什么情况下出错。这里有一张表，里面列出了使用我的USB驱动需要了解的和其有紧密关系的指令。   | Table 5.1 Keyboard related functions in CSUD | | | | | --- | --- | --- | --- | | **Function** | **Arguments** | **Returns** | **Description** | | UsbInitialise | None | r0 is result code | This method is the all-in-one method that loads the USB driver, enumerates all devices and attempts to communicate with them. This method generally takes about a second to execute, though with a few USB hubs plugged in this can be significantly longer. After this method is completed methods in the keyboard driver become available, regardless of whether or not a keyboard is indeed inserted. Result code explained below. | | UsbCheckForChange | None | None | Essentially provides the same effect as UsbInitialise, but does not provide the same one time initialisation. This method checks every port on every connected hub recursively, and adds new devices if they have been added. This should be very quick if there are no changes, but can take up to a few seconds if a hub with many devices is attached. | | KeyboardCount | None | r0 is count | Returns the number of keyboards currently connected and detected. UsbCheckForChange may update this. Up to 4 keyboards are supported by default. Up to this many keyboards may be accessed through this driver. | | KeyboardGetAddress | r0 is index | r0 is address | Retrieves the address of a given keyboard. All other functions take a keyboard address in order to know which keyboard to access. Thus, to communicate with a keyboard, first check the count, then retrieve the address, then use other methods. Note, the order of keyboards that this method returns may change after calls to UsbCheckForChange. | | KeyboardPoll | r0 is address | r0 is result code | Reads in the current key state from the keyboard. This operates via polling the device directly, contrary to the best practice. This means that if this method is not called frequently enough, a key press could be missed. All reading methods simply return the value as of the last poll. | | KeyboardGetModifiers | r0 is address | r0 is modifier state | Retrieves the status of the modifier keys as of the last poll. These are the shift, alt control and GUI keys on both sides. This is returned as a bit field, such that a 1 in the bit 0 means left control is held, bit 1 means left shift, bit 2 means left alt, bit 3 means left GUI and bits 4 to 7 mean the right versions of those previous. If there is a problem r0 contains 0. | | KeyboardGetKeyDownCount | r0 is address | r0 is count | Retrieves the number of keys currently held down on the keyboard. This excludes modifier keys. Normally, this cannot go above 6. If there is an error this method returns 0. | | KeyboardGetKeyDown | r0 is address, r1 is key number | r0 is scan code | Retrieves the scan code (see Table 4.1) of a particular held down key. Normally, to work out which keys are down, call KeyboardGetKeyDownCount and then call KeyboardGetKeyDown up to that many times with increasing values of r1 to determine which keys are down. Returns 0 if there is a problem. It is safe (but not recommended) to call this method without calling KeyboardGetKeyDownCount and interpret 0s as keys not held. Note, the order or scan codes can change randomly (some keyboards sort numerically, some sort temporally, no guarantees are made). | | KeyboardGetKeyIsDown | r0 is address, r1 is scan code | r0 is status | Alternative to KeyboardGetKeyDown, checks if a particular scan code is among the held down keys. Returns 0 if not, or a non-zero value if so. Faster when detecting particular scan codes (e.g. looking for ctrl+c). On error, returns 0. | | KeyboardGetLedSupport | r0 is address | r0 is LEDs | Checks which LEDs a particular keyboard supports. Bit 0 being 1 represents Number Lock, bit 1 represents Caps Lock, bit 2 represents Scroll Lock, bit 3 represents Compose, bit 4 represents Kana, bit 5 represents Power, bit 6 represents Mute and bit 7 represents Compose. As per the USB standard, none of these LEDs update automatically (e.g. Caps Lock must be set manually when the Caps Lock scan code is detected). | | KeyboardSetLeds | r0 is address, r1 is LEDs | r0 is result code | Attempts to turn on/off the specified LEDs on the keyboard. See below for result code values. See KeyboardGetLedSupport for LEDs' values. |   结果代码是一种简单的处理错误的方式。但常常会有更加优雅的解决方案存在于更高层次的代码中。  一些函数返回“结果代码”。这在C语言中，算是老生常谈了。这些结果代码表示在一次函数调用中发生了什么。方便起见，0总是表示成功。我们的驱动使用到了下面所列的结果代码。   | Table 5.2 - CSUD Result Codes | | | --- | --- | | **Code** | **Description** | | 0 | Method completed successfully. | | -2 | Argument: A method was called with an invalid argument. | | -4 | Device: The device did not respond correctly to the request. | | -5 | Incompatible: The driver is not compatible with this request or device. | | -6 | Compiler: The driver was compiled incorrectly, and is broken. | | -7 | Memory: The driver ran out of memory. | | -8 | Timeout: The device did not respond in the expected time. | | -9 | Disconnect: The device requested has disconnected, and cannot be used. |   本驱动的一般用法依下列各项：  1. 调用UsbInitialise  2. 调用UsbCheckForChange  3. 调用KeyboardCount  4. 如果结果为0，返回到第二步。  5. 对于每一个键盘，你要提供以下支持：  1. 调用KeyboardGetAddress  2. 调用KeybordGetKeyDownCount  3. 对于每个按键的按下：  1. 检测是否被按下  2. 把按下的键存储起来  4. 对于每个存储的按键：  1. 检测是否被释放  2. 如果被释放，就清楚它  6. 依据按键被按下或者被释放来执行指令  7. 返回到第二步。  最终，你可以实现任何你对键盘的想法。并且这些函数应该允许你去接触到它的功能。在后面的2个课程中，我们将会看到一个文本终端的输入端的完成过程，这个文本终端和大多数的命令行计算机很类似，它们都是解释命令的。为了做到这些，我们需要让键盘输入使用一种更加有效的形式。你可能已经注意到了，我的驱动帮助不是太大（我故意的）。这是因为我的驱动并没有一个函数来推断出一个按键是否刚刚被按下或者释放。它仅仅是有一个表示什么刚才被按下的函数。这意味着我们要自己动手编写一个那样的函数。   1. 更新可用   为了更新反复地进行检测被称为“测验”。这个和中断性驱动IO截然相反。后者只是在数据准备好以后，才会给系统发送一个信号。  首先，让我们实现一个方法，给它一个名字KeyboardUpdate，用它来检测第一个键盘，并使用它的测验方法来获得刚才的输入。为了比较还需要把最后一个输入存储起来。然后，我们可以使用这个数据，配合使用别的函数，来把扫描代码转换成按键信息。该函数应该精确地做如下步骤：  1. 恢复一个被存储的按键地址（初始为0）。  2. 如果这个不是0， 直接调转到第九步。  3. 调用UsbCheckForChange来检测新键盘。  4. 调用KeyboardCount来检测当前有多少个键盘。  5. 如果结果是0，那就把该地址存储为0并返回。没有键盘我们什么也做不了。  6. 调用KeyboardGetAddress，配合参数0来得到第一个键盘的地址。  7. 存储这个地址。  8. 如果是0，返回；可能出了什么错误。  9. 调用KeyboardGetKeyDown函数6次，以便得到当前每个按下的按键，并把它们存储起来。  10. 调用KeyboardPoll。  11. 如果结果是非零的，返回到第三步。可能出错了（比如键盘链接断开）。  为了存储上面提到的数值，我们需要在.data节里的这些值。  .section .data .align 2 KeyboardAddress: .int 0 KeyboardOldDown: .rept 6 .hword 0 .endr  .hword num指令的意思是把常数num的半字直接插入到文件里。  .rept num [commands] .endr 指令的意思是把命令commands拷贝到输出，循环执行num次。  试着自己先实现这些函数看看。我的实现列在下面。  .section .text .globl KeyboardUpdate KeyboardUpdate: push {r4,r5,lr}  kbd .req r4 ldr r0,=KeyboardAddress ldr kbd,[r0]  我们加载键盘的地址。  teq kbd,#0 bne haveKeyboard$  如果地址非零，那就意味着我们拥有一个键盘。调用UsbCheckForChanges函数是缓慢的。所以，当没一样都在工作时，我们就应该避免它。  getKeyboard$: bl UsbCheckForChange  如果我们还没有键盘，我们就不得不去检测是否有新的键盘。  bl KeyboardCount  现在，我们就来看看是否有新的键盘已经插入。  teq r0,#0 ldreq r1,=KeyboardAddress streq r0,[r1] beq return$  没有键盘的话，键盘地址信息也就不存在。  mov r0,#0 bl KeyboardGetAddress  让我们获得第一个键盘的地址。你可能想要准许更多的键盘。    ldr r1,=KeyboardAddress str r0,[r1]  存储键盘的地址。  teq r0,#0 beq return$ mov kbd,r0  如果我们没有地址，就没有更多的事情要做。  saveKeys$:  mov r0,kbd mov r1,r5 bl KeyboardGetKeyDown  ldr r1,=KeyboardOldDown add r1,r5,lsl #1 strh r0,[r1] add r5,#1 cmp r5,#6 blt saveKeys$  对所有的键盘进行轮询。把它们的地址存储在KeyboardOldDown函数中。如果我们征求更多的地址，这个函数就会返回0，以预示它工作良好。  mov r0,kbd bl KeyboardPoll  现在，我们获得了新的键。  teq r0,#0 bne getKeyboard$  return$: pop {r4,r5,pc} .unreq kbd  最终，如果函数KeyboardPoll起作用，我们就检测。如果不起作用，我们可能已经断开了链接。  在我们新的函数KeyboardUpdate函数的帮助下，检测输入就很简单了。简单到只需要在规律的时间间隔内调用这个函数，同时还要检测是否断开链接等。这是一个很有用的函数。由于我们的实际按键处理程序可能和基于状态的处理程序不同，那么仅仅利用一个函数调用就可以获得当前输入的原始格式一般情况下很适用的。从理想的角度看，我们需要的下一个函数是KeyboardGetChar，一个简单地返回下一个按下的键的ASCII字符，如果没有按下任何键，就只返回0。这可以扩展到支持一种新的情况，当我们按下一个键的并持续一段时间后，可以输入这个字符多次，同时也可以支持“lock”按键修饰符。  如果我们有一个KeyWasDown函数就更好了。如果一个给定的扫描码并没有在KeyboardOldDown函数的值里，就简单地返回0，其他情况下，返回一个非零值。试试自己实现一下。和之前的一样，下载页里可以找到这个函数的一个解决方案。  7. 查表  在编程的许多方面，程序的体量越大，它的执行速度就越快。查表的程序的体量虽然很大，但是它的执行速度却很快。许多问题的解决就依赖于混合使用查表和普通的函数。  KeyboardGetChar函数的实现如果很糟糕的话，它就会非常的复杂。这里有100个扫描码，每一个带有不同效果的扫描码依赖于shift按键或者其他按键修饰符是否按下或者没有。并不是所有的按键可以转化为一个字符。对于一些字符来说，多个按键可以产生相同的字符。一个很有用的技巧就是查表，它可以完全适应这种有很多种可能的情况。一张表和它的物理意义一样，罗列着值和它们的相应的结果。对于一些速度受限的函数来说，解决方案中最简单的方法是提前计算每一个问题的答案，并把它们的问题答案对保存在一张表格中。当问题来临，我们不是进行计算而是在表格中寻找。在这个例子中，我们先在内存中预先建立一个值的序列。当需要知道扫描码n对应的ASCII码是什么字符时，就去这个序列中查找第n个值即可。也就是说我们的函数将只是简单地检测哪个按键被按下，然后在表格中寻找起对应的值。进一步讲，我们可以为shift按键被按下时对应的键值建立一个独立的单独的表格，这样便于我们独立地设置表格中的值。  在命令.section .data之后，把下面的表格追加上：  .align 3 KeysNormal:  .byte 0x0, 0x0, 0x0, 0x0, 'a', 'b', 'c', 'd' .byte 'e', 'f', 'g', 'h', 'i', 'j', 'k', 'l' .byte 'm', 'n', 'o', 'p', 'q', 'r', 's', 't' .byte 'u', 'v', 'w', 'x', 'y', 'z', '1', '2' .byte '3', '4', '5', '6', '7', '8', '9', '0' .byte '\n', 0x0, '\b', '\t', ' ', '-', '=', '[' .byte ']', '\\', '#', ';', '\'', '`', ',', '.' .byte '/', 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, '/', '\*', '-', '+' .byte '\n', '1', '2', '3', '4', '5', '6', '7' .byte '8', '9', '0', '.', '\\', 0x0, 0x0, '='  .align 3 KeysShift:  .byte 0x0, 0x0, 0x0, 0x0, 'A', 'B', 'C', 'D' .byte 'E', 'F', 'G', 'H', 'I', 'J', 'K', 'L' .byte 'M', 'N', 'O', 'P', 'Q', 'R', 'S', 'T' .byte 'U', 'V', 'W', 'X', 'Y', 'Z', '!', '"' .byte '£', '$', '%', '^', '&', '\*', '(', ')' .byte '\n', 0x0, '\b', '\t', ' ', '\_', '+', '{' .byte '}', '|', '~', ':', '@', '¬', '<', '>' .byte '?', 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0 .byte 0x0, 0x0, 0x0, 0x0, '/', '\*', '-', '+' .byte '\n', '1', '2', '3', '4', '5', '6', '7' .byte '8', '9', '0', '.', '|', 0x0, 0x0, '='  命令.byte num的意思是把字节常量num的值直接插入到文件里。  大多数汇编器和编译器可以识别escape序列、字符序列（例如\t的意思是插入一个特殊的字符来代替。）  这些表格把头104个扫描码直接映射到ASCII字符，以字节为单位。 |