Computer Labs: The PC Keyboard

2º MIEIC

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PC Keyboard Operation: Data Input

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The KBC Commands

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Lab 3: The PC's Keyboard - Part 1

- Write functions:

  ```
  int kbd_test_scan()
  int kbd_test_poll()
  ```

  that require programming the PC's keyboard controller
  - Compare the number of `sys_inb()` kernel calls
- These functions are not the kind of functions that you can reuse later in your project
  - The idea is that you design the lower level functions (with the final project in mind).
  - Reusable code should go on a different files from non-reusable code.
- What's new?
  - Program the KBC controller (i8042)
  - In part 2:
    - Handle interrupts from more than one device

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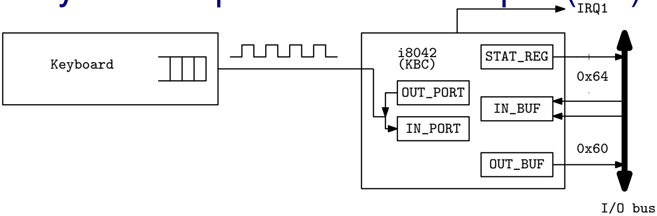
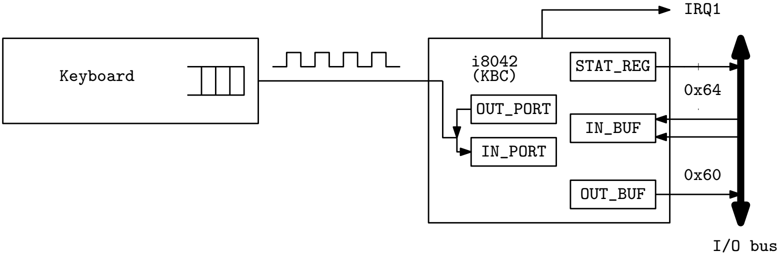
PC Keyboard Operation: Data Input (1/2)



- The keyboard has its own controller chip (not shown): the controller@KBD (C@KBD)
- When a key is pressed the C@KBD generates a **scancode (make code)** and puts it in a buffer for sending to the PC
  - **Usually, a scancode is one byte long**
- The same happens when a key is released
  - Usually, the scancode when a key is released (**break code**) is the make code of that key with the MSB set to 1
- The communication between the C@KBD and the PC is via a serial line
  - I.e. the bits in a byte are sent one after the other over a pair of wires

PC Keyboard Operation: Data Input (2/2)



- On the PC side this communication is managed by the keyboard controller (KBC)
  - In modern PCs, the KBC is integrated in the motherboard chipset
- When **`OUT_BUF`** (@ port 0x60) is empty:
  1. The KBC signals that via the serial bus
  2. The C@KBD sends the byte at the head of its buffer to the KBC
  3. The KBC puts it in the `OUT_BUF`
  4. The KBC generates an interrupt by raising `IRQ1`

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Lab 3: `kbd_test_scan()` (1/2)

What Prints the scancodes, both the **makecode** and the **breakcode**, read from the KBC

- Should terminate when it reads the **breakcode** of the `ESC` key: `0x81`
- The first byte of two byte scancodes is usually `0xE0`
  - This applies to both make and break codes

How Need to subscribe the KBC interrupts

- Upon an interrupt, read the scancode from the `OUT_BUF`

Note There is no need to configure the KBC

- It is already initialized by Minix

Issue Minix already has an IH installed

- Must be disabled to prevent it from reading the `OUT_BUF` before your handler does it

Solution Use not only the `IRQ_REENABLE` but also the `IRQ_EXCLUSIVE` policy in `sys_irqsetpolicy()`, i.e. use `IRQ_REENABLE|IRQ_EXCLUSIVE`

Lab 3: `kbd_test_scan()` (2/2)

KBC interrupt subscription in exclusive mode;

`driver_receive()` loop (similar to that of lab 2)

Interrupt handler reads the bytes from the KBC's `OUT_BUF`

- Should read only **one byte per interrupt**
  - The communication between the keyboard and the KBC is too slow
- Should check whether there was some error (see below)
- Should not print the scancodes (not reusable)
- In the project, you may think about including the code that maps the scancodes to a character code
  - IH in Minix are usually out of the critical path
    - They are executed with interrupts enabled and after issuing the EOI command to the PIC
  - In many systems this may not be appropriate. For example, in Linux most DD break interrupt handling in two:

    Top half which is in the critical path, and therefore does minimal processing

    Bottom half which is not in the critical path

Lab 3: Counting the number of sys_inb() calls

Issue You do not want this feature in the project

Solution Use #ifdef for conditional compilation. Alternatives:

Use #ifdef before/after every sys_inb()/util_sys_inb() call

```
#define LAB3
sys_inb(...);
#ifdef LAB3
cnt++;
#endif
```

Use wrapper function util_sys_inb()

- You already call it instead of sys_inb()
- Need only to increment counter, if LAB3 is defined

In both cases add line to Lab3's Makefile

```
CPPFLAGS += -D LAB3
```

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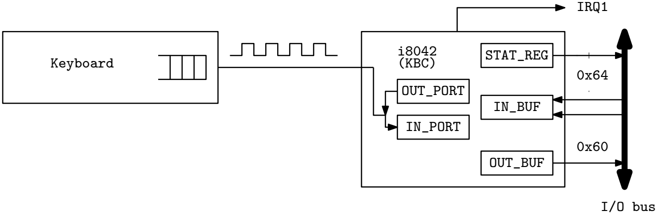
The KBC Commands (of the PC-AT)



- The KBC added a few commands, the **KBC commands**, and two new registers at port `0x64`

  Status Register for reading the KBC state
  Not named for writing KBC commands

  - Apparently, this is not different from the `IN_BUF` at port `0x60`
  - The value of input line `A2` is used by the KBC to distinguish KBC commands from KBD commands
  - That is: the KBC has **only one** writable register, the `IN_BUF`

Status Register

- Both KBC's input and output require reading the status register

Bit	Name	Meaning (if set)
7	Parity	Parity error - invalid data
6	Timeout	Timeout error - invalid data
5	Aux	Mouse data
4	INH	Inhibit flag: 0 if keyboard is inhibited
3	A2	A2 input line: irrelevant for LCOM
2	SYS	System flag: irrelevant for LCOM
1	IBF	Input buffer full don't write commands or arguments
0	OBF	Output buffer full - data available for reading

- Bits 7 and 6 signal an error in the (serial) communication between the keyboard and the KBC
  - **Should check them in the IH**
  - Should always read the `OUT_BUF`, but discard in case of error
- Do not write to the `IN_BUF`, if bit 1, i.e. the `IBF`, is set.

Keyboard-Related KBC Commands for PC-AT/PS2

- These commands must be written using address `0x64`
  - Arguments, if any, must be passed using address `0x60`
  - Return values, if any, are passed in the `OUT_BUF`

Command	Meaning	Args (A)/ Return (R)
`0x20`	Read Command Byte	Returns Command Byte
`0x60`	Write Command Byte	Takes A: Command Byte
`0xAA`	Check KBC (Self-test)	Returns 0x55, if OK Returns 0xFC, if error
`0xAB`	Check Keyboard Interface	Returns 0, if OK
`0xAD`	Disable KBD Interface	
`0xAE`	Enable KBD Interface	

KBD Interface is the serial interface between the keyboard and the KBC

- Disabling of the KBD interface is achieved by driving the clock line low.

- There are several other KBC-commands related to the mouse (and also to the keyboard)

(KBC "Command Byte")

7	6	5	4	3	2	1	0
–	–	DIS2	DIS	–	–	INT2	INT

`DIS2` 1: disable mouse interface

`DIS` 1: disable keyboard interface

`INT2` 1: enable interrupt on OBF, from mouse;

`INT` 1: enable interrupt on OBF, from keyboard

`-` : Either not used or not relevant for Lab

Read Use KBC command 0x20, which must be written to `0x64`

- But the value of the "command byte" must be read from `0x60`

Write Use KBC command 0x60, which must be written to `0x64`

- But the new value of the "command byte" must be written to `0x60`

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KBC Registers: Summary

Status Register @ address 0x64

- Read the KBC state

Input Buffer @ either address 0x64 or address 0x60. Can be used to **write**:

Commands to the KBC access via address 0x64;

Arguments of KBC commands access via address 0x60

Output Buffer @ address 0x60. Can be used to **read**:

Scandcodes both make and break, received from the keyboard;

Return values from KBC commands;

Note These addresses belong to the I/O address space

- Need to use `IN/OUT` assembly instructions or the library functions `sys_inb()/sys_outb()` of the kernel API

Issuing a Command to the KBC

```
#define KBC_ST_REG  0x64
#define KBC_CMD_REG 0x64

while( 1 ) {
    sys_inb(KBC_ST_REG, &stat); /* assuming it returns OK */
    /* loop while 8042 input buffer is not empty */
    if( (stat & KBC_ST_IBF) == 0 ) {
        sys_outb(KBC_CMD_REG, cmd); /* no args command */
        return 0;
    }
    delay(WAIT_KBC); // e.g. tickdelay()
}
```

Note 1 Cannot output to the `0x64` while the input buffer is full

Note 2 Code leaves the loop only when it succeeds to output the data to the `0x64`

- To make your code resilient to failures in the KBC/keyboard, it should give up after “enough time” for the KBC to send a previous command/data to the KBD.

Reading Return Value/Data from the KBC

```
#define KBC_OUT_BUF 0x60

while( 1 ) {
    sys_inb(KBC_ST_REG, &stat); /* assuming it returns OK */
    /* loop while 8042 output buffer is empty */
    if( stat & KBC_OBF ) {
        sys_inb(KBC_OUT_BUF, &data); /* ass. it returns OK */

        if ( (stat &(KBC_PAR_ERR | KBC_TO_ERR)) == 0 )
            return data;
        else
            return -1;
    }
    delay(WAIT_KBC); // e.g. tickdelay()
}
```

Note 1 Code leaves the loop only upon some input from the `KBC_OUT_BUF`.

- It is not robust against failures in the KBC/keyboard

Note 2 Must mask IRQ1, otherwise the keyboard IH may run before we are able to read the `KBC_OUT_BUF`

KBC Programming Issues

Interrupts If the command has a response, and interrupts are enabled, the IH will “steal” them away from other code

- The simplest approach is to disable interrupts.

Timing KBD/KBC responses are not immediate.

- Code needs to wait for long enough, but not indefinitely

Concurrent Execution The C@KBD continuously scans the KBD and may send scancodes, while your code is writing commands to the KBC:

- How can you prevent accepting a scancode as a response to a command?
    - It is easier to solve this for KBC commands than for KBD commands.
    - Assume that all scancode bytes generated by the KBD are different from the KBD responses

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Lab 3: `kbd_test_poll()`

What? Read the scan codes by polling

How? Keep polling the status register (`0x64`), and, if `OBF` is set and `AUX` is cleared, read the OB

- The function `lcf_start()` already disables keyboard interrupts by the KBC (this also prevents Minix's keyboard IH from "stealing" the scan codes)
- Must enable interrupts by writing **command byte** before exiting
  - Should read the **command byte** before to restore it later

Hint Try to design a solution based on layers that allows you to issue any KBC command, not just command `0x20`/`0x60`

Bottom layer Functions that read/write the KBC registers. Deals with the details of the KBC HW interface. E.g.:

- Checks the `IBF` flag before writing

Top layer Functions to issue either KBC commands

- Knows about the commands and the protocol, writing parameters as necessary and waiting for responses

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Lab 3: `kbd_test_timed_scan(uint8_t idle)`

What Similar to `kbd_test_scan()` except that process should terminate, upon:

either release of the ESC key

or after `idle` seconds, during which no scancode is received

How Must subscribe interrupts both of the keyboard and the timer/counter

- Must handle both interrupts in the "`driver_receive()` loop"

```
switch (_ENDPOINT_P(msg.m_source)) {
case HARDWARE: /* hardware interrupt notification */
    if (msg.m_notify.interrupts & timer0_int_bit) { // Timer0 int?
        ... /* process Timer0 interrupt request     */
    }
    if (msg.m_notify.interrupts & kbd_int_bit) { // KBD int?
        ... /* process KBD interrupt request  */
    }
    break;
default:
    break; /* no other notifications expected: do nothing */
}
```

- Must not change timer 0's configuration

Lab 3: 2019/2020 Grading Criteria

SVN (5%) Whether or not your code is in the right place (under `lab3/`, of the repository's root)

- Also, evidence of incremental development approach

Execution (65%) Make sure you test your code thoroughly

Code (30%)

code organization reusable and non-reusable code in $\neq$ files

layering the higher the layer, the less knowledge about the KBC/keyboard interface is required

handling keyboard responses consider also cases of HW failure

See also the criteria used in the code evaluation of lab 2.

Self-evaluation **Must fill Google form** (check the handout)

Further Reading

- IBM's Functional Specification of the 8042 Keyboard Controller (IBM PC Technical Reference Manual)
- W83C42 Data Sheet, Data sheet of an 8042-compatible KBC
- Andries Brouwer's The AT keyboard controller, Ch. 11 of Keyboard scancodes
- Andries Brouwer's Keyboard commands, Ch. 12 of Keyboard scancodes