Advanced Computer Architecture

Lecture No. 26

Reading Material

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Computer Systems Design and Architecture	8.2.2

Summary

- The Centronic Parallel Printer Interface(Cont.)
- Programmed Input/Output
- Examples of Programmed I/O for FALCON-A and SRC
- Comparisons of FALCON-A, SRC examples

The Centronic Parallel Printer Interface (Cont.)

Table 1: The Centronics Parallel Printer Interface
(power and ground signals are not shown)
(The explanation of this table is provided in lecture 25 also)

Signal Name	**Direction w.r.t. Printer**	**Function Summary**	**Pin# (25-DB) CPU side**	**Pin# (36-DB) Printer side**
D<7..0>	Input	8-bit data bus	9,8,…,2	9,8,…,2
STROBE#	Input	1-bit control signal High: default value. Low: read-in of data is performed.	1	1
ACKNLG#	Output	1-bit status signal Low: data has been received and the printer is ready to accept new data. High: default value.	10	10
BUSY	Output	1-bit status signal Low: default value High: see note#1	11	11
PE#	Output	1-bit status signal High: the printer is out of paper. Low: default value.	12	12
INIT#	Input	1-bit control signal Low: the printer controller is reset to its initial state and	16	31

		the print buffer is cleared. High: default value.		
SLCT	Output	1-bit status signal High: the printer is in selected state.	13	13
AUTO FEED XT#	Input	1-bit control signal Low: paper is automatically fed after one line.	14	14
SLCT IN#	Input	1-bit control signal Low: data entry to the printer is possible. High: data entry to printer is not Possible.	17	36
ERROR#	Output	1-bit status signal Low: see note#2. High: default value.	15	32

Table 2: Centronics Bit Assignment For I/O Ports

Logical Address	**Description**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
0	8-bit output port for DATA	D<7>	D<6>	D<5>	D<4>	D<3>	D<2>	D<1>	D<0>
1	8-bit input port for STATUS	BUSY	ACKNLG#	PE#	SLCT	ERROR#	Unused	Unused	Unused
2	8-bit output port for CONTROL	Unused	Unused	DIR[16]	IRQEN	SLCT IN#	INIT#	Auto Feed XT#	STROBE#

[16] This bit, when set, enables the bidirectional mode.

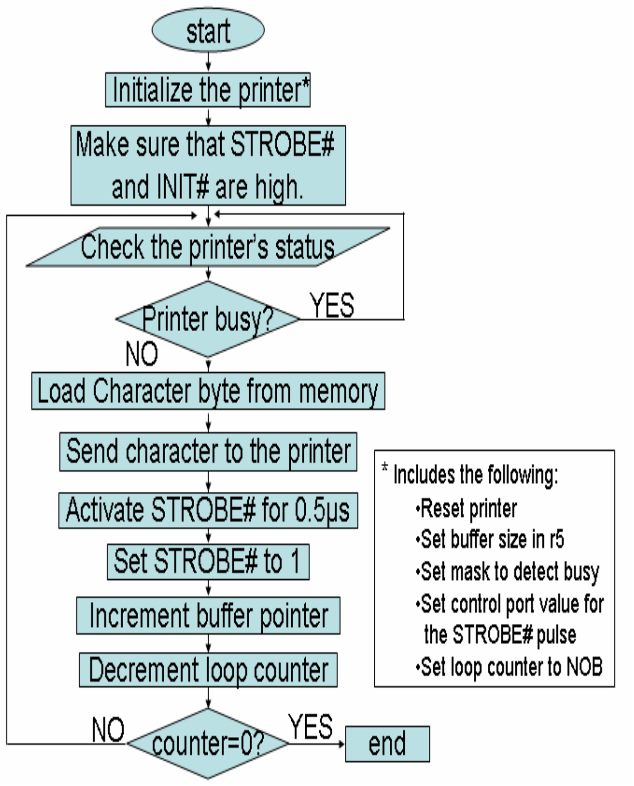
Example # 1

Problem statement:

Assuming that a Centronics parallel printer is interfaced to the FALCON-A processor, as shown in example 3 of lecture 25, write an assembly language program to send an 80 character line to the printer. Assume that the line of characters is stored in the memory starting at address 1024.

Solution:

The flowchart for the solution is shown in given figure and the program listing is shown in the textbox with filename: Example_1.


start
Initialize the printer*
Make sure that STROBE# and INIT# are high.
Check the printer's status
Printer busy?
YES
NO
Load Character byte from memory
Send character to the printer
Activate STROBE# for 0.5μs
Set STROBE# to 1
Increment buffer pointer
Decrement loop counter
NO
counter=0?
YES
end
* Includes the following:
•Reset printer
•Set buffer size in r5
•Set mask to detect busy
•Set control port value for the STROBE# pulse
•Set loop counter to NOB

The first thing that needs to be done is the initialization of the printer. This means that a "reset" command should be sent to the printer. Using the information from Table 1, this can be done by writing a 0 to bit 2 (i.e., INIT#) of the control register having logical address 2. In our example, this maps onto address 60 of the FALCON-A. (Remember to set this bit to logic 1 for normal operation of the printer). Then we make STROBE# high by placing logic 1 in bit 0 of the control register. Bit 1 and bit 3 should be 0 because we want to activate auto line feed and keep the printer in selected mode. Additionally, bit 4 and bit 5 should be 0 so that interrupts are disabled and the bi-directional mode is not selected. The complete control word is 0000 0001 and this value has been assigned to the variable reset in the program. The following instruction pair performs the reset operation:

```
movi r1, reset
out r1, controlp
```

As it is given that the starting address of the printer buffer is 1024[17], so we place this address in r5. The mask to test the BUSY flag is placed in r3. The value for the mask is 80h. This corresponds to a logic 1 in bit 7 and logic zeros elsewhere for the status register having address 58 (logical address 1 in Table 1). Then the program enters a loop, called the polling loop, to test the status of the printer. If the printer is busy, the loop repeats. The following three instructions form the polling loop:

```
in r1, statusp
and r1, r1, r3
jnz r1, [again]
```

[17] The **mul** instruction is used for this purpose because the 8-bit immediate operand in the **movi** instruction can only be within the range –128 and +127. Using the **mul** instruction in this way overcomes the limitation of the FALCON-A. Similarly, the **shiftl** instruction is used to bring 80h in register r3.

The status of the printer is placed in register r1, and bit 7 is tested for logic 0. If not so, the program repeats the status check operation.

When the printer is ready to accept a new character, it clears bit 7 (i.e., the BUSY bit) of the status register. At this time, the program picks the next character from the memory and sends it to the printer. The STROBE# line is activated and then it is deactivated to generate the necessary pulse on this input of the printer. Finally, the buffer pointer is advanced, the loop counter is decremented and the process repeats. When all the characters have been printed, the program halts.
A number of equates have been used in the program to make it flexible as well as easily readable. The program is shown on the next page.

```
; filename: Example_1.asmfa
;
; This program sends an 80 character line
; to a FALCON-A parallel printer
;
; Notes:
; 1.  8-bit printer data bus connected to
;     D<7...0> of the FALCON-A (remember big-endian)
;     Thus, the printer actually uses addresses 57, 59 & 61
;
; 2.  one character per 16-bits of data xfered
;
;
      .org 400
;
NOB:        .equ  80
;
      movi r5, 32
      mul r5, r5, r5    ; r5 holds 1024 temporarily
;
      movi r3, 1
      shiftl r3, r3, 7  ; to set mask to 0080h
;
datap:      .equ 56
statusp:    .equ 58
controlp:   .equ 60
;
reset:            .equ 1
; used to set unidirectional, no interrupts,
; auto line feed, and strobe high
;
strb_H:           .equ 5
strb_L:           .equ 4
;
      movi r1 reset     ; use r1 for data xfer
      out r1, controlp
;
      movi r7, NOB      ; use r7 as character counter
;

again:      in r1, statusp
;
      and r1, r1, r3    ; test if BUSY = 1?
      jnz r1, [again]   ; wait if BUSY = 1
;
      load r1, [r5]
      out r1, datap
      movi r1, strb_L
      out r1, controlp
      movi r1, strb_H
      out r1, controlp
      addi r5, r5, 2
      subi r7, r7, 1
      jnz r7, [again]
      halt
```

I/O techniques:

There are three main techniques using which a CPU can exchange data with a peripheral device, namely

- Programmed I/O
- Interrupt driven I/O
- Direct Memory Access (DMA).

In this section, we present the first one.

Programmed Input/Output

Programmed I/O refers to the situation when all I/O operations are performed under the direct control of a program running on the CPU. This program, which usually consists of a "tight loop", controls all I/O activity, including device status sensing, issuing read or write commands, and transferring the data[18]. A subsequent I/O operation cannot begin until the current I/O operation to a certain device is complete. This causes the CPU to wait, and thus makes the scheme extremely inefficient. The solution to Example # 3(lec24), Example #2(lec25), and Example #1(lec26) are examples of programmed input/output. We will analyze the program for Example #1(lec26) to explain a few things related to the programmed I/O technique.

Timing analysis of the program in Example # 1(lec26)

The main loop of the program given in the solution to Example #1(lec26) executes 80 times. This is equal to the number of characters to be printed on one line. This portion of the program is shown again with the execution time of each instruction listed in brackets with it. The numbers shown are for a uni-bus CPU implementation. A complete list of execution times for all the FALCON-A's instructions is given in Appendix A. A number of things can be noted now.

```
         movi r7, NOB          [2]
;
again:   in r1, statusp        [3]
         and r1 , r1, r3       [3]
         jnz  r1, [again]      [4]
;
         load r1, [r5]         [5]
         out r1, datap         [3]
         movi r1, strob_L      [2]
         out r1, controlp      [3]
         movi r1, s trob_H     [2]
         out r1, controlp      [3]
         addi r5, r5, 2        [3]
         subi r7, r7, 1        [3]
         jnz r7, [again]       [4]
         halt
```

1. Assuming that the output at the hardware pins changes at the end of the (I/O write) bus cycle, the STROBE# signal will go from logic1 to logic 0 at the end of the instruction pair.

```
movi r1, strb_L        [2]
out r1, controlp       [3]
```

[18] The I/O device has no direct access to the memory or the CPU, and transfer is generally done by using the CPU registers.

The execution time for these two instructions is 2+3 = 5 clock periods. Therefore, STROBE# stays at logic1 for at least 5 clock periods i.e., during these two instructions. For a 10MHz FALCON-A CPU, this will correspond to 5x100 = 500nsec = 0.5µsec. Since the data to the printer is being sent by the CPU using the two instructions (**load r1, [r5]** and **out r1, datap**) which are before the first **movi** instruction, the printer's data setup time requirement is satisfied as long as we do not increase the clock frequency beyond 10MHz.

After these two instructions, the next two instructions in the program cause STROBE# to go to logic 1 again.

```
movi r1, strb_H        [2]
out r1, controlp       [3]
```

These two instructions also take 5 clock periods, or 0.5µsec, to execute. Thus, the timing requirement of the STROBE# pulse width will also be satisfied as long as we do not increase the clock frequency beyond 10MHz. In case the frequency is greater than 10MHz, other instruction can be used in between these two pairs of instructions.

The printer's data hold time requirement is easily satisfied because there are a number of instructions after this **out** instruction which do not change the control port, and the character value is already present in the data register within the interface since the end of the **out r1, datap** instruction.

2. The three instructions given below:

```
again:  in r1, statusp   [3]
        and r1, r1, r3   [3]
        jnz r1, [again]  [4]
```

form what is called a "polling loop". The process of periodically checking the status of a device to see if it is ready for the next I/O operation is called "polling". It is the simplest way for an I/O device to communicate with the CPU. The device indicates its readiness by setting certain bits in a status register, and the CPU can read these bits to get information about the device. Thus, the CPU does all the work and controls all the I/O activities. The polling loop given above takes 10 clock periods. For a 10MHz FALCON-A CPU, this is 10x100=1µsec. One pass of the main loop takes a total of 3+3+4+5+3+2+3+2+3+3+3+4 = 38 clock periods which is 38x100 = 3.8µsec. This is the time that the CPU takes to send one character to the printer. If we assume that a 1000 character per second (cps) printer is connected to the CPU, then this printer has the capability to print one character in every 1msec or every 1000µsec. So, after sending a character in 3.8µsec to the printer, the CPU will wait for about 996µsec before it can send the next character to the printer. This implies that the polling loop will be executed about 996 times for each character. This is indeed a very inefficient way of sending characters to the printer.

An improved way of doing this would be to include a memory of suitable size within the printer. This memory is also called a buffer, as explained earlier. The CPU can fill this buffer in a single "burst" at its own speed, and then do something else, while the printer picks up one character at a time from this buffer and prints it at its own speed. This is exactly the situation with today's printers. The task of generating the STROBE# pulse will also be done by the electronic circuits within the printer. In effect, a dedicated processor within the printer will do this job. However, if the buffer within the printer fills up, the CPU will still not be able to transfer additional data to it. A different handshaking scheme will then be needed to make the CPU to communicate asynchronously with the buffer in the printer, resulting in an inefficient operation again. This is explained below.

Assume that the printer has a FIFO type buffer of size 64 bytes that can be filled up without any delay at the time when the printer is not printing anything. When one or more character values are present in the buffer, the printer will pick up one value at a time and print it. Remember we have a 1000 cps printer, so it takes 1msec to print a character. The program for Example #1(lec26) is modified for this situation and is given below. All the assumptions are the same, unless otherwise mentioned.

```
again:      in r1, statusp   [3]
            and r1, r1, r3   [3]
            jnz  r1, [again] [4]
            load r1, [r5]    [5]
            out r1, datap    [3]
            addi r5, r5, 2   [3]
            subi r7, r7, 1   [3]
            jnz r7, [again]  [4]
```

Note that while the instructions for generating the STROBE# pulse have been eliminated, the polling loop is still there. This is necessary because the BUSY signal will still be present, although it will have a different meaning n now. In this case, BUSY =1 will mean that the buffer within the printer is full and it can not accept additional bytes.

The main loop shown in the program has an execution time of 28 clock periods, which is 2.8µsec for a 10MHz FALCON-A CPU. The polling loop still takes 10 clock periods or 1µsec. Assuming that this program starts when the buffer in the printer is empty, the outer loop will execute 64 times before the CPU encounters a BUSY=1 condition. After that the situation will be the same as in the previous case. The polling loop will execute for about 996 times before BUSY goes to logic 0. This situation will persist for the remaining 16 characters (remember we are sending an 80 character line to the printer).

One can argue that the problem can be solved by increasing the buffer size to more than 80 bytes. Well, first of all, memory is not free. So, a large buffer will increase the cost of the printer. Even if we are willing to pay more for an improved printer, the larger buffer will still fill up whenever the number of characters is more than the buffer size. When that happens, we will be back to square one again.

A careful analysis of the situation reveals that there is something wrong with the scheme that is being used to send data to the printer. This problem of having a larger overhead of polling was recognized long ago, and therefore, interrupts were invented as an alternate to programmed I/O. Interrupt driven I/O will be the topic of the next lecture.

Programmed I/O in SRC

In this section, we will discuss some more examples of programmed I/O with our example processor SRC which uses the memory mapped I/O technique.

Program for Character Output

To understand how programmed I/O works in SRC, we will discuss a program which outputs the character to the printer. The first instruction loads the branch target and the second instruction loads the character into lower 8 bits of register r2. The 2-instruction loop reads the status register and tests the ready signal by checking its sign bit. It executes until the ready signal becomes logic one. On exit from the loop, the character is written to the device data register by the store instruction.

```
      lar r3, wait
      ldr r2, char
wait: ld r1, COSTAT
      brpl r3, r1
      st r2, COUT
```

A 10 MIPS, SRC would execute 10,000 instructions waiting for a 1,000 character/sec printer.

Program Fragment to Print 80-Character Line

The next example for the SRC is of a program which sends an 80-character line to a line printer with a command register. There are two nested loops starting at label wait. The two instruction inner loop, which waits for ready and the outer seven instruction loop which performs the following tasks.

- Outputs a character
- Advance the buffer pointer
- Decrement the register containing the number of characters left to print
- Repeat if there are more characters left to send.

The last two instructions issue the command to print the line.
The next example discussed from the book is of a driver program for 32-character input devices (Figure 8.10, Page 388).

Comparisons of the SRC and FALCON-A Examples

The FALCON-A and SRC programmed I/O examples discussed are similar with some differences. In the first example discussed for the SRC (i.e. Character output), the control signal responsible for data transfer by the CPU is the ready signal while for FALCON-A Busy (active low)signal is checked. In the second example for the SRC, the instruction set, address width and no. of lines on address is different.
Although different techniques have been used to increase the efficiency of the programmed I/O, overheads due to polling can not be completely eliminated.