Laboratory Exercise 2

Using Logic Instructions with the ARM Processor

Logic instructions are needed in many embedded applications. Logic instructions are useful for manipulation of bit strings and for dealing with data at the bit level where only a few bits may be of special interest. They are essential in dealing with input/output tasks. In this exercise we will consider some typical uses. We will use the ARM Cortex-A9 processor in the DE0-Nano-SoC Computer.

Part I

In this part you will implement an ARM assembly language program that counts the longest string of 1's in a word of data. For example, if the word of data is `0x103fe00f`, then the required result is 9.

Perform the following:

1. Create a new folder to hold your Monitor Program project for this part. Create a file called *part1.s*, and type the assembly language code shown in Figure 1 into this file. This code uses an algorithm involving shift and AND operations to find the required result—make sure that you understand how this works.
2. Make a new Monitor Program project in the folder where you stored the *part1.s* file. Use the DE0-Nano-SoC Computer for this project.
3. Compile and load the program. Fix any errors that you encounter (if you mistyped some of the code). Once the program is loaded into memory in the DE0-Nano-SoC Computer, single step through the code to see how the program works.

Part II

Perform the following.

1. Make a new folder and make a copy of the file *part1.s* in that new folder. Give the new file a name such as *part2.s*.
2. In the new file *part2.s*, take the code which calculates the number of consecutive 1's and make it into a subroutine called ONES. Have the subroutine use register R1 to receive the input data and register R0 for returning the result.
3. Add more words in memory starting from the label TEST_NUM. You can add as many words as you like, but include at least 10 words. To terminate the list include the word 0 at the end—check for this 0 entry in your main program to determine when all of the items in the list have been processed.
4. In your main program, call the newly-created subroutine in a loop for every word of data that you placed in memory. Keep track of the longest string of 1's in any of the words, and have this result in register R5 when your program completes execution.

5. Make sure to use breakpoints or single-stepping in the Monitor Program to observe what happens each time the ONES subroutine is called.

```
/* Program that counts consecutive 1's */
            .text
            .global   _start
_start:
            LDR       R1, TEST_NUM  // load the data word into R1

            MOV       R0, #0        // R0 will hold the result
LOOP:       CMP       R1, #0        // loop until the data contains no more 1's
            BEQ       END
            LSR       R2, R1, #1    // perform SHIFT, followed by AND
            AND       R1, R1, R2
            ADD       R0, #1        // count the string lengths so far
            B         LOOP

END:        B         END

TEST_NUM:   .word     0x103fe00f

            .end
```

Figure 1: Assembly-language program that finds the largest string of 1's.

Part III

One might be interested in the longest string of 0's, or even the longest string of alternating 1's and 0's. For example, the binary number 101101010001 has a string of 6 alternating 1's and 0's.

Write a new assembly language program that determines the following:

- Longest string of 1's in a word of data—put the result into register R5
- Longest string of 0's in a word of data—put the result into register R6
- Longest string of alternating 1's and 0's in a word of data—put the result into register R7 (Hint: What happens when an n-bit number is XORed with an n-bit string of alternating 0's and 1's?)

Make each calculation in a separate subroutine called ONES, ZEROS, and ALTERNATE. Call each of these subroutines in the loop that you wrote in Part III, and keep track of the largest result for each calculation, from your list of data.

Part IV

In this part you are to extend your code from Part III so that the results produced are shown on the Terminal window of the Altera Monitor Program. Each result should be displayed as a two-digit decimal number preceded by the name of the register the number corresponds to. You may want to use the approach discussed in Part IV of Exercise 1 to convert the numbers in registers R5, R6, and R7 from binary to decimal.

The DE0-Nano-SoC Computer can communicate with the Altera Monitor Program's Terminal through the JTAG UART. The programming interface of the JTAG UART consists of two 32-bit registers, as shown in Figure 2. The register mapped to address 0xFF201000 is called the *Data* register and the register mapped to address 0xFF201004 is called the *Control* register.

The JTAG UART includes a 64-character FIFO that stores data waiting to be transmitted to the host computer. ASCII character data is loaded into this FIFO by performing a write to bits 7-0 of the Data register in Figure 2. Note that writing into this register has no effect on received data. The amount of space, WSPACE, currently available in the transmit FIFO is provided in bits 31-16 of the Control register. If the transmit FIFO is full, then any characters written to the Data register will be lost. A subroutine that transmits a character to the host computer is shown in Figure 3.

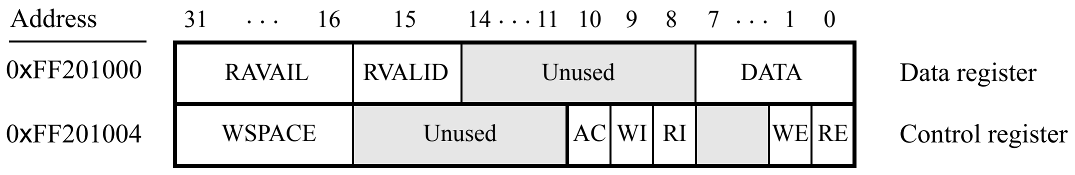


Figure 2: The JTAG UART Programming Interface.

An example of code that shows the contents of registers on the Terminal window is illustrated in Figure 4. The code in the figure shows only the steps needed to display the contents of register R5 on the Terminal. Extend the code to display the contents of all three registers.

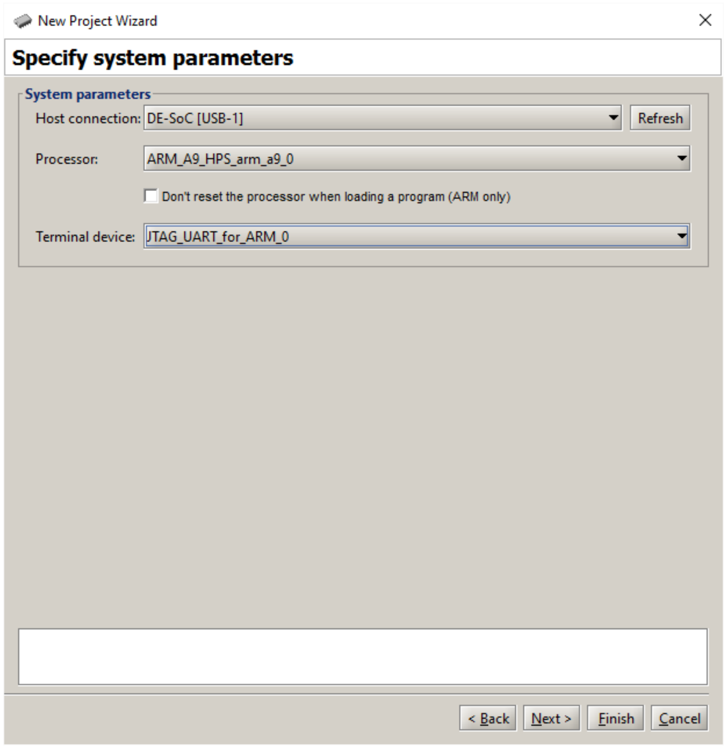
```
/********************************************************************************
 * Subroutine to send a character to the JTAG UART
 * R0 = character to send
********************************************************************************/
PUT_JTAG:   LDR     R1, =0xFF201000         // JTAG UART base address
            STR     R0, [R1]                // send the character
END_PUT:    BX      LR
```

Figure 3: A subroutine that sends an ASCII character to the Monitor Program Terminal.

```
. . .
code for Part III (not shown)
. . .
/* Display R5, R6 and R7 on the Terminal */
DISPLAY:      LDR      R0, =PRINT_R5
              BL       PRINT_STR           // print the string

SHOW_R5:      MOV      R0, R5              // display content of R5 on the Terminal
              BL       PRINT_REG           // print the decimal digits
              . . .
              code for printing “R6:” and decimal value of R6 (not shown)
              . . .
              code for printing “R7:” and decimal value of R7 (not shown)
              . . .
/* Subroutine to send a null-terminated string to the JTAG UART
 *    input: R0 contains the address of the string */
PRINT_STR:    LDR      R2, =0xFF201000     // JTAG UART base address
JTAG_LOOP:    LDRB     R1, [R0], #1        // get the next character
              . . .
END_PRINT:    MOV      PC, LR

/* Subroutine to ”print” the decimal value of a register to the JTAG Terminal
 *    input: R0 is the register to be converted to decimal and displayed */
PRINT_REG:    PUSH     {LR}
              BL       DIVIDE              // ones digit will be in R0; tens digit in R1
              LDR      R2, =0xFF201000     // JTAG UART base address
              . . .
              POP      {PC}

              . . .

PRINT_R5:     .asciz   ”R5: ”
              .skip    3       // pad with 3 bytes to maintain word alignment
PRINT_R6:     .asciz   ”R6: ”
              .skip    2       // pad with 2 bytes to maintain word alignment
PRINT_R7:     .asciz   ”R7: ”
              .skip    3       // pad with 3 bytes to maintain word alignment
```

Figure 4: A code fragment for showing registers in decimal on the Terminal window.

For your Monitor Program project for this part, in the screen shown in Figure 5, make sure to select JTAG_UART_for_ARM_0 as the *Terminal device*. Without this setting no character output will appear on the Terminal window when your code writes to the JTAG UART.



Host connection: DE-SoC [USB-1]

Processor: ARM_A9_HPS_arm_a9_0

☐ Don't reset the processor when loading a program (ARM only)

Terminal device: JTAG_UART_for_ARM_0

Figure 5: Specifying the *Terminal device*.