COE 301 / ICS 233

Computer Organization

Exam 1 – Spring 2017

Saturday, March 18, 2017

10 AM – 12 Noon

Computer Engineering Department

College of Computer Sciences & Engineering

King Fahd University of Petroleum & Minerals

Student Name: **SOLUTION**

Student ID:

Section:

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| --- | --- | --- | --- |
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Important Reminder on Academic Honesty

Using unauthorized information or notes on an exam, peeking at others work, or altering graded exams to claim more credit are severe violations of academic honesty. Detected cases will receive a failing grade in the course.

**Question 1: Fill-in the Blanks**

**a)** (2 pts) Imagine that you are working for a company that fabricates a certain IC chip. The cost per wafer is $3000, and each wafer has 2000 dies. If the cost of a good die is $2.50,then the yield of this manufacturing process is **($3000/$2.50)/2000 = 0.6 or 60%**.

1. (2 pts) Given that the instruction **j NEXT** is at address **0x004000F4**, and the label **NEXT** is at address **0x00402AEC**. Then, the 26-bit immediate stored in the jump instruction for the label **NEXT** is **0x00402AEC >> 2 = 0x0100ABB**.

**c)** (3 pts) Given the following data definitions, the address of the first variable **X** is given at **0x10010000** (hexadecimal), the hexadecimal addresses for **Y**, **Z**, and **S** will be:

**.data**

**X: .half 1, 2, 3**

**Y: .byte 'A', 'B', 'C'**

**Z: .word 7, 8, 9**

**.ALIGN 3**

**S: .asciiz "STRING"**

**Address of Y =** **0x10010006**

**Address of Z =** **0x1001000C**

**Address of S =** **0x10010018**

**d)** (3 pts) Show the MIPS assembly language instruction that is equivalent to the following machine language instruction. Provide the immediate value in **decimal**. The MIPS Reference data sheet is attached at the end.

|  |  |
| --- | --- |
| **Machine language instruction** | **MIPS assembly language instruction** |
| **0011 0001 0001 0001 1000 0111 0110 0101** | **Op=ANDI, Rs=$8, Rt=$17, I=34661****ANDI $s1, $t0, 34661** |

**e)** (5 pts) Each square in the table shown below represents one byte in memory and each row stores 8 bytes in memory. Starting at address **0×10010000** in the data segment, show the **byte content** in memory in **hexadecimal** for the following data definitions. If a byte is not used (or uninitialized) then leave it empty. Fill only the bytes that are initialized. For words and half words, the little endian byte ordering should be used.

**.DATA**

**.WORD -2**

**.HALF 0×1FFF**

**.ALIGN 2**

**.BYTE 11:3**

**.ALIGN 4**

**.BYTE 13, -1**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Address** | **+0** | **+1** | **+2** | **+3** | **+4** | **+5** | **+6** | **+7** |
| **0×10010000** | **0xFE** | **0xFF** | **0xFF** | **0xFF** | **0xFF** | **0x1F** |  |  |
| **0×10010008** | **0x0B** | **0x0B** | **0x0B** |  |  |  |  |  |
| **0×10010010** | **0x0D** | **0xFF** |  |  |  |  |  |  |
| **0×10010018** |  |  |  |  |  |  |  |  |

**f)** (5 pts) Given the following contents of memory, where each square represents only one byte in memory, show the values of registers **$t0** thru **$t4** in **hexadecimal** after executing each of the following MIPS assembly language instructions. The little endian byte ordering should be used. Assume **$s0 =** **0×10010020**.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Address** | **+0** | **+1** | **+2** | **+3** | **+4** | **+5** | **+6** | **+7** |
| **0×10010020** | **0xFA** | **0x20** | **0x10** | **0xC0** | **0xB0** | **0x5F** | **0x94** |  |

|  |  |
| --- | --- |
| **lw $t0, 0($s0)** | **$t0 = 0xC01020FA** |
| **lh $t1, 2($s0)** | **$t1 = 0xFFFFC010** |
| **lhu $t2, 4($s0)** | **$t2 = 0x00005FB0** |
| **lb $t3, 5($s0)** | **$t3 = 0x0000005F** |
| **lbu $t4, 6($s0)** | **$t4 = 0x00000094** |

**Question 2: Pseudo-Instructions**

For each of the following pseudo-instructions, produce a **minimal** sequence of basic MIPS instructions to accomplish the same thing. You may use the **$at** register only as a temporary register.

**a)** **abs $t1, $t2 # absolute value (4 pts)**

**addu $t1, $t2, $zero # $t1 = $t2**

**bgez $t2, done**

**subu $t1, $zero, $t2 # $t1 = -$t2**

**done:**

**# Solution 2: No branch**

**sra $at, $t2, 31 # $at = 0 or -1 (0xFFFFFFFF)**

**xor $t1, $t2, $at # $t1 = $t2 or 1’s complement**

**subu $t1, $t1, $at # $t1 = $t2 or 2’s complement**

**b)** **addiu $t1, $t2, 0x1234abcd # 32-bit constant (4 pts)**

**lui $at, $0x1234 # $at = 0x12340000**

**ori $at, $at, $0xabcd # $at = 0x1234abcd**

 **addu $t1, $t2, $at**

**c)** **bgt $t1, 100, Label # branch if greater than 100 (3 pts)**

**ori $at, $zero, 100**

 **slt $at, $at, $t1**

 **bne $at, $zero, Label**

 **# Better solution**

 **slti $at, $t1, 101**

 **beq $at, $zero, Label**

**d)** **ror $t1, $t2, 15 # rotate right value of $t2 15 bits (4 pts)**

**sll $t1, $t2, 17**

**rotate right**

**srl $at, $t2, 15**

**or $t1, $t1, $at**

**Question 3: Trace the Execution of the following Code**

**a)** (7 pts) Given that **Array** is defined as shown below, determine the content of registers **$v0** and **$v1** after executing the following code. **Explain what the program does**.

**Array: .word 15, -19, 17, 20, -10, 12, 100, -5**

 **la $a0, Array # $a0 = 0x10010000**

 **addi $a1, $a0, 28**

 **move $v0, $a0**

 **lw $v1, 0($v0)**

 **move $t0, $a0**

**loop: addi $t0, $t0, 4**

 **lw $t1, 0($t0)**

 **bge $t1, $v1, skip**

 **move $v0, $t0**

 **move $v1, $t1**

**skip: bne $t0, $a1, loop**

**$v0 = 0x10010004 (address of minimum element)**

**$v1 = -19 (minimum value)**

 **The program is determining the minimum element in the array and its address in memory.**

1. (8 pts) Given that **Array** is defined as shown below, determine the content of **Array** after executing the following code. **Explain what the program does.**

**Array: .half 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12**

 **la $a0, Array**

 **li $a1, 6**

 **move $t0, $a0**

 **addi $t1, $a0, 12**

**loop: lh $t3, ($t0)**

 **lh $t4, ($t1)**

 **sh $t3, ($t1)**

 **sh $t4, ($t0)**

 **addi $t0, $t0, 2**

 **addi $t1, $t1, 2**

 **addi $a1, $a1, -1**

 **bne $a1, $zero, loop**

**New Array Content:**

 **7, 8, 9, 10, 11, 12, 1, 2, 3, 4, 5, 6**

 **The program is swapping the first six array elements with the last six**

**Question 4: Writing MIPS code**

(15 pts) Write a MIPS loop thatconverts a string to lower case. The address of the string exists in register **$a0**. The string is terminated with a null character. The string should be read, converted, and stored in memory. Check each character if it is an upper case letter (range **'A'** to **'Z'**) before converting it to lower case. Recall that **'A' = 0x41** and **'a' = 0x61**.

**move $t0, $a0 # $t0 = string pointer**

**loop: lb $t1, 0($t0) # load $t1 = character**

 **blt $t1, 'A', skip # not a capital letter**

 **bgt $t1, 'Z', skip # not a capital letter**

 **addi $t1, $t1, 0x20 # convert to lowercase**

 **sb $t1, 0($t0) # store lowercase letter**

**skip: addi $t0, $t0, 1 # advance pointer**

 **bne $t1, $zero, loop # loop if not null character**

**Question 5: Translating Nested Loops into MIPS Assembly Language**

(20 pts) Translate the following nested loops into MIPS assembly language. Register **$a0** stores the number **n** of elements in all arrays, **$a1** = addressofthe array **a[]**, **$a2** = addressofthe array **b[]**, and **$a3** = addressofthe array **c[]**. Each array element is a 32-bit signed integer. Insert comments to clarify the meaning of instructions and the use of registers.

 **for (i=0; i != n; i++) {**

 **int cnt = 0;**

 **for (j=0; j != n; j++) {**

 **if (a[i] == b[j]) cnt = cnt + 1;**

 **}**

 **c[i] = cnt;**

 **}**

**Solution:**

 **li $t0, 0 # $t0 = i = 0**

**for1: # outer for loop**

 **li $t1, 0 # cnt = 0**

 **li $t2, 0 # $t2 = j = 0**

 **lw $t3, 0($a1) # load $t3 = a[i]**

 **move $t4, $a2 # $t4 = address of b**

**for2: # inner for loop**

 **lw $t5, 0($t4) # load $t5 = b[j]**

 **bne $t3, $t5, skip # skip if a[i] != b[j]**

 **addiu $t1, $t1, 1 # cnt = cnt + 1**

**skip:**

 **addiu $t4, $t4, 4 # point to next b[j]**

 **addiu $t2, $t2, 1 # j++**

 **bne $t2, $a0, for2 # loop back if j!=n**

 **sw $t1, 0($a3) # store c[i] = cnt**

 **addiu $a1, $a1, 4 # point to next a[i]**

 **addiu $a3, $a3, 4 # point to next c[i]**

 **addiu $t0, $t0, 1 # i++**

 **bne $t0, $a0, for1 # loop back if i!=n**

**Question 6: The Transposition of a Matrix**

(20 pts) Transposition is an important matrix operation. Given that matrix **A** is a square matrix of integers with dimensions **n×n**, the transposition is accomplished by swapping matrix element **A[i][j]** with element **A[j][i]**, as shown in the following nested loops. Given that register **$a0=n**, and register **$a1** = **address** of matrix **A**, translate the following nested loops into MIPS assembly language code.

 **for (i=0; i != n; i++) {**

 **for (j=i+1; j != n; j++) {**

 **temp1 = A[i][j];**

 **temp2 = A[j][i];**

 **A[i][j] = temp2;**

 **A[j][i] = temp1;**

 **}**

 **}**

Outer for loop has only (*n* – 1) iterates, because when *i* is (*n* – 1) the inner for loop will have zero iterates.

**Solution:**

 **li $t0, 0 # $t0 = i = 0**

 **addiu $t9, $a0, -1 # $t9 = n-1 (iterates outer for)**

**for1: # outer for loop**

 **addiu $t1, $t0, 1 # $t1 = j = i+1**

**for2: # inner for loop**

 **mul $t2, $t0, $a0 # $t2 = i\*n**

 **addu $t2, $t2, $t1 # $t2 = i\*n + j**

 **sll $t2, $t2, 2 # $t2 = (i\*n + j) \* 4**

 **addu $t2, $a1, $t2 # $t2 = &A[i][j]**

 **mul $t3, $t1, $a0 # $t3 = j\*n**

 **addu $t3, $t3, $t0 # $t3 = j\*n + i**

 **sll $t3, $t3, 2 # $t3 = (j\*n + i) \* 4**

 **addu $t3, $a1, $t3 # $t3 = &A[j][i]**

 **lw $t4, 0($t2) # $t4 = A[i][j]**

 **lw $t5, 0($t3) # $t5 = A[j][i]**

 **sw $t5, 0($t2) # A[i][j] = $t5**

 **sw $t4, 0($t3) # A[j][i] = $t4**

 **addiu $t1, $t1, 1 # j++**

 **bne $t1, $a0, for2 # loop back if j!=n**

 **addiu $t0, $t0, 1 # i++**

 **bne $t0, $t9, for1 # loop back if i!=(n-1)**

**Better Solution: Faster Traversal of Matrix by Rows and by Columns**

 **li $t0, 0 # $t0 = i = 0**

 **sll $t7, $a0, 2 # $t7 = n\*4 (bytes per row)**

 **addiu $t8, $t7, 4 # $t8 = n\*4 + 4 (bytes)**

 **addiu $t9, $a0, -1 # $t9 = n-1 (iterates outer for)**

**for1: # outer for loop**

 **addiu $t1, $t0, 1 # $t1 = j = i+1**

 **addiu $t2, $a1, 4 # $t2 = &A[i][j]**

 **addu $t3, $a1, $t7 # $t3 = &A[j][i]**

**for2: # inner for loop**

 **lw $t4, 0($t2) # $t4 = A[i][j]**

 **lw $t5, 0($t3) # $t5 = A[j][i]**

 **sw $t5, 0($t2) # A[i][j] = $t5**

 **sw $t4, 0($t3) # A[j][i] = $t4**

 **addiu $t2, $t2, 4 # $t2 = &A[i][j] (by row)**

 **addu $t3, $t3, $t7 # $t3 = &A[j][i] (by column)**

 **addiu $t1, $t1, 1 # j++**

 **bne $t1, $a0, for2 # loop back if j!=n**

 **addu $a1, $a1, $t8 # $a1 = &A[i][i] (main diagonal)**

 **addiu $t0, $t0, 1 # i++**

 **bne $t0, $t9, for1 # loop back if i!=(n-1)**

**Smaller inner loop: 8 instructions per inner loop iterate versus 14 used in first solution.**

**No multiply instruction is used for address calculation in the second solution.**

**Any solution that works is acceptable.**