Written Exam / Tentamen

Computer Organization and Components / Datorteknik och komponenter (IS1500), 9 hp
Computer Hardware Engineering / Datorteknik, grundkurs (IS1200), 7.5 hp

KTH Royal Institute of Technology

2019-06-05

08.00-13.00

Suggested Solutions

Part I: Fundamentals

In part I, on the real exam, only short answers are expected. The elaborated answers given here are just for your information, and are not needed on the real exam.

1. **Module 1: C and Assembly Programming**

   (a) Short answer: `unknown 35 ffffffff 5a9b1748`

   Max 4 points. One point for each correct answer.

   (b) Short answer: i) `0x3c0832a1` and ii) `0x32a10000`

   Note that for ii), the `lui` instruction is executed as the last instruction. Hence, the 16 least significant bits are all zero.

   Max 4 points. i) Three points for completely correct machine code, two points if at most one byte is incorrect, and one point if at most two bytes are incorrect. ii) One point for the correct hexadecimal value.

2. **Module 2: I/O Systems**

   (a) Short answer:

   i. The pointers should be declared using the `volatile` keyword.

   ii. One possible solution is as follows:

```
getvals:
        addi    $v0,$zero,0
        lui     $t1,0x1001
while:
        lw      $t0,0x40($t1)
        andi    $t0,$t0,1
        beq     $t0,$zero,exit
        lw      $v0,0x50($t1)
        srl     $v0,$v0,4
        andi    $v0,$v0,0xf
        j       while
exit:
        jr      $ra
```

   iii. The function will exit when push button number 1 is released (not pushed)

   iv. When push button 1 is released, the 4-bit value formed by the status of switches 4, 3, 2, and 1 is returned.

Max 8 points in total, given as follows:

i. One point for just stating the `volatile` keyword. (Max 1 point)

ii. In the code, one point is given for setting up the return value to be 0 (if the while loop exits directly). One point for loading correctly from the two addresses, including using `lui`. One point for `andi` and correctly exiting the loop using `beq` or similar. One point for shifting correctly four bits to the right and masking the four bits using `andi`. One point for correctly jumping back to the `while` label, and returning from the function using `jr`. (Max 5 points)

iii. One point for a reasonable description. (Max 1 point)

iv. One point for a reasonable description. (Max 1 point)

3. **Module 3: Logic Design (for IS1500 only)**

   (a) Short answer: $Y_0 = 1$, $Y_1 = 0$, $Y_2 = 0$, and $N = 2$

   Max 4 points. One point for each correct answer.

   (b) Short answer: The sum-of-products form is $\overline{A}\,\overline{B}C + A\overline{B}C + ABC$

   Max 2 points. Two points if correct (can be in a different form). One point if there is one error in one of the products.

   (c) Short answer: 32 bits

   Elaborated answer: A read port is 6 bits wide, which means that there are $2^6 = 64$ different registers in the register file. Since the register file can store 2048 bits in total, each register is $2048/64 = 32$ bits. Hence, 32 bits can be written to the register file in parallel.

   Max 2 points. Two points for a correct answer.

4. **Module 4: Processor Design**

   (a) Short answer: $A =$ `0x8`, $B =$ `0x18`, $C =$ `0x0`, $D =$ `unknown`, and $E =$ `0x15`.

   Max 5 points. One point for each correct answer.

   (b) Short answer:

   i. The data hazard is between `lw` and `beq`.

   ii. Yes, stalling is needed. 2 clock cycles.

   iii. The value is 5 because the branch delay slot executes the `addi` instruction after the `beq` instruction when the branch is taken.

   Max 3 points. One point for each correct answer.

5. **Module 5: Memory Hierarchy**

   (a) Short answer: i) 8 bytes, ii) 256 bits, and iii) 22 bits.

   Elaborated answers:

   i. Since there are 128 sets, there are in total $128 \cdot 2 = 256$ blocks. Hence, the block size is $2048/256 = 8$ bytes.

   ii. For each block, there is one valid bit. Hence, there are in total 256 valid bits.

   iii. Since the block size is 8 bytes, the byte offset field is 3 bits. Also, since there are 128 sets, the set field size is 7 bits. Hence, the tag size is $32 - 7 - 3 = 22$ bits.

   Max 3 points. One point for each correct answer.

   (b) Short answer: i) 100%, 40%, and iii) spatial locality.

   i. There are in total 2 data accesses using the `lw` instruction. Moreover, each block in the data cache is $2048/256 = 8$ bytes. The first address that is accessed is `0x33002214` and results in a cache miss. The second access is on address `0x33002218`, which is another set. Hence, we get 2 cache misses and two data accesses. The data cache miss rate is therefore 100%.

   ii. There is a cache miss in the instruction cache when the first instruction is loaded at address `0x00030200`. However, the bock size is 16 bytes, and therefore 4 instructions are loaded due to the miss. This means that the following 3 memory accesses are instruction cache hits. The last instruction is in a new set and results in a miss. Hence, the instruction cache miss rate is $\frac{2}{5}$, that is 40%.

   iii. The instruction cache only shows spatial locality because each access is only accessed once.

6. **Module 6: Parallel Processors and Programs**

   (a) Short answer: The maximal speedup is 2.5.

   Elaborated answer: Using Amdahl's law, we get the maximal speedup

   $$\frac{1}{\frac{0.6}{N} + 0.4} = 2.5 \quad \text{when} \quad N \to \infty \tag{1}$$

   Max 3 points. Give 3 points for the correct answer, else 0 points.

   (b) Short answers:

   i. True.

   ii. True.

   iii. False. Semaphores can be used to handle e.g. shared resources in concurrent programming, whereas the cache coherence problem concerns a problem that occurs in multicore systems with caches.

   iv. True.

   v. True.

   Max 5 points. One point for each correct answer. The false statements need to have clear motivations.

Part II: Advanced

7. The complete solution is omitted. Please see the lecture slides and the course book.

   Max 15 points. For each of the three items, max three points for the explanations of the two concepts, max one point for at least one difference, and max one point for at least one similarity. That is, max five points for each of the three items.

8. The following two functions are examples of possible solutions.

```
int match(const char* key1, const char* key2){
  while(*key1 != 0 && *key2 != 0){
    if(*key1 != *key2){
       return 0;
    }
    key1++;
    key2++;
  }

  if(*key1 == 0 && *key2 == 0)
    return 1;
  else
    return 0;
}

void insert(char* key, int value){
  *(keys + elements) = key;
  *(values + elements) = value;
  elements++;
}
```

   Max 18 points in total.

9. The following MIPS code is a possible solution, without any optimizations.

```
find:
        addi    $sp,$sp,-12         # Save sp & s0 on the stack
        sw      $ra,8($sp)
        sw      $s1,4($sp)
        sw      $s0,0($sp)

        addi    $s0,$a0,0           # save argument, so that it is not
                                    # desroyed by the call to match

        addi    $s1,$zero,0         # counter i = $s1
for:
        la      $t0,elements        # load the number of elements.
        lw      $t0,0($t0)          # Direct translation, not optimized
        beq     $s1,$t0,exitfor

        la      $t0,keys            # Load the key from the array
        sll     $t1,$s1,2
        add     $t0,$t0,$t1
        lw      $a0,0($t0)
        addi    $a1,$s0,0
        jal     match               # call the match function
        beq     $v0,$zero,nomatch   # skip if no match
        la      $t0,values
        sll     $t1,$s1,2
        add     $t0,$t0,$t1
        lw      $v0,0($t0)
        j       exitfind
nomatch:
        addi    $s1,$s1,1           # Go to next element
        j       for

exitfor:                            # No match found, return -1
        addi    $v0,$zero,-1
exitfind:                           # exit the function,
        lw      $s0,0($sp)          # pop from stack
        lw      $s1,4($sp)
        lw      $ra,8($sp)
        addi    $sp,$sp,12
        jr      $ra
```

Max 17 points in total.

Correction of the Exam

The examiner David Broman authored the exam questions, the correction guidelines, and the suggested solutions. The following persons took part in the correction: Saranya Natarajan, Viktor Palmkvist, Daniel Lundén, and Fredrik Lundevall.