02155 - Computer architecture and Engineering
Fall 2022

Assignment 1

Group 31

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This report contains 8 pages

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A1.1

Figure 1: Problem a.

```
ADDI t0, x0, 8      // Sets temporary register to 8
REM t0, x4, t0      // Uses signed remainder ops similar to modulus.
BNE x0, t0, skip    // If x4 mod 8 is not 0, then x4 is not a multiple of 8.
ADD x1, x0, x0      // Set x1 to 0 when x4 mod 8 was actully 0.
skip:
NOP
```

Figure 2: Problem b. Bit mask way (Personal preference)

```
ANDI x1, x5, 31      // Applies an immediate bit mask on x5 stored in x1
```

Figure 3: Problem b. Remainder way

```
ADDI t0, x0, 32     // Sets temporary register to 32 for REM.
REM x1, x4, t0      // Uses signed remainder ops similar to modulus.
```

A1.2

Figure 4: Vector reader program

```
ADDI t0, x0, 0x10000    // Using t0 as read address for number in vector
ADDI t1, x0, 1          // Using t1 as index i starting at 1
ADDI t2, x0, 100        // Using t2 for stop condition
LW a0, 0(t0)            // Init smalest number as first number
LW a1, 0(t0)            // Init largest number as first number

LOOP:
BEG t1, t2, END         // End when i reach 100, meaning all numbers are read
LW t3, 4(t0)            // Load number from vector (but skip first)

BGE t3, a1, BIGGER      // Branch if number is largest so far
BLT t3, a0, SMALLER     // Branch if number is smalest so far
BNE x0, x0, CONTINUE

BIGGER:
ADD a1, x0, t3         // Set largest number seen so far
BNE x0, x0, CONTINUE

SMALLER:
ADD a0, x0, t3         // Set smalest number seen so far

CONTINUE:
ADD t1, t1, 1           // Increment i by one (i++)
ADDI t0, t0, 4          // Increment address to next number (4 bytes)
BNE x0, x0, LOOP        // Always branch to start of loop.

END:
NOP
```

A1.3

a.

Determining the execution time of the program can be found by finding total amount of cycles and dividing by the clock rate using the following equation.

$$\frac{\textbf{CPU Clock Cycles}}{\textbf{Clock rate}} = \textbf{CPU Time}$$

Using given information to get execution time.

$$\frac{10^6 \cdot 0.35 \cdot 3 + 10^6 \cdot 0.4 \cdot 4 + 10^6 \cdot 0.25 \cdot 5}{2000000000} = 0.00195$$

b.

Using same equation, with new given information to get execution time.

$$\frac{10^6 \cdot 0.35 \cdot 3 + 10^6 \cdot 0.35 \cdot 4 + 10^6 \cdot 0.25 \cdot 5 + 10^6 \cdot 0.05 \cdot 6}{2000000000} = 0.002$$

With a 500 micro seconds longer execution time, the modifications are not advantageous for the benchmark.

A1.4

Disclaimer: The intention and idea of this exercise was very hard for me to understand, and clarification was not available for me. Therefor a best attempt with the following assumptions was made

- *... contains operations to facilitate calee save strategy*
- *... contains no operations that alter registers besides those used to fulfill calee save strategy*
- *... contains operations that always save and restore saved registers regardless of usage*
- *The PC location is instruction addresess*
- *Only saved registers and return adress is saved and restored from the stack*
- *Only used saved registers will be saved to the stack*
- *Unused stack space has been zeroed*
- *The first ... contains no operations that push values to the stack and at that point the stack is empty at the assumed initialization.*
- *add or lw does not implicitly push to the stack*
- *Restoration of temporary registers do not zero the memory*

Address	**168**	**240**	**260**	**360**	**364**	**388**	**280**	**176**
0x10000:	0	176	176	176	176	176	176	176
0xFFFC:	0	18	18	18	18	18	18	18
0xFFF8:	0	16	16	16	16	16	16	16
0xFFF0:	0	4	4	4	4	4	4	4
0xFFEC:	0	2	2	2	2	2	2	2
0xFFE8:	0	0	0	264	264	264	264	264
0xFFE0:	0	0	0	4	4	4	4	4

The temporary variables that are set from 152 to 168, would need to be saved and restored by the calee ie. push to stack instructions at the beginning of procedure B, and restoration instructions before jalr at instr addr 300. The temporary variable used at instr addr 240, would also require a push and restoration from the stack, thus pushing instructions first thing in procedure C and restoration last thing before 388. The stack does not change much after PC arrives at 360, that is because it is assumed we reached the leaf procedure and now only need to restore temporary variables for the caller. Popping values from the stack does not zero the memory, which is why the stack stays mostly the same after 360, but the stack pointer will be changing after each jalr instruction.

I don't feel confident that i've captured the intention in this answer and suggest the exercise description is revisited if reused.

A1.5

Figure 5: Complex multiplication program

```
        .data
aa :    .word a # Re part of z
bb :    .word b # Im part of z
cc :    .word c # Re part of w
dd :    .word d # Im part of w

        .text
        .globl main
main :
    lw a0, aa
    lw a1, bb
    lw a2, cc
    lw a3, dd
    jal ra, complexMul # Multiply z and w
    nop
    j end # Jump to end of program
    nop

complexMul:
    MUL t0, a0, a2
    MUL t1, a1, a3
    MUL t2, a0, a3
    MUL t3, a1, a2
    SUB a0, t0, t1
    ADD a1, t2, t3
    jalr x0, 0(ra)

end:
    nop
```

a.

The procedure *complexMul* is a leaf procedure, as it does not call any other procedures.

b.

The stack was not used, as complex multiplication was achievable with reasonable convinience without the need to retain local variables that a non-leaf procedure needs. For example, no need to store return address or other temporary values that will be needed after secondary procedure call returns.

c.

4 MUL instructions contribute 8 cycles, sub, add and jalr contribute 3 cycles, which totals 11 cycles.

A1.6

Figure 6: Alternative Ccmplex multiplication program

```
        .data
aa :    .word a # Re part of z
bb :    .word b # Im part of z
cc :    .word c # Re part of w
dd :    .word d # Im part of w

        .text
        .globl main
main :
    lw a0, aa
    lw a1, bb
    lw a2, cc
    lw a3, dd
    jal ra, altComplexMul # Multiply z and w
    nop
    j end # Jump to end of program
    nop

altComplexMul:
    ADD t0, a0, a1
    MUL t0, t0, a2
    SUB t1, a3, a2
    MUL t1, t1, a0
    ADD t2, a2, a3
    MUL t2, t2, a1
    SUB a0, t0, t2
    ADD a1, t0, t1
    jalr x0, 0(ra)

end:
    nop
```

a.

altComplexMul is a leaf procedure as it does not call another procedure.

b.

The stack is not used as there was no need to save return address, temporaries or any values from registers that might be overwritten in a nested procedure call.

c.

3 MUL instructions contribute 6 cycles, 3 ADD instructions contribute 3 cycles, 2 SUB instructions contribute 2 cycles and jalr contribute one cycle, totaling 12 cycles

A1.7

a.

If RISC-V only had 2 argument registers and one result register, I would store the arguments in memory and pass the address of the arguments rather than the actual values. To return the results, again the results could be stored in memory and address to the results would be given instead of actual values. This way composite structures like imaginary numbers, but also other structures that contain multiple values like strings can be used. Both techniques are fundamental when looking at procedure call patterns: **Call By Reference** and **Call By Value** that is used in higher level programming languages.

b.

No registers are saved across a procedure call without additional instructions. Only registers that is put in the stack or stored elsewhere in memory with instructions will be protected from potential overwrites. It is convention to save and restore return address and used temporaries to x8-x9 and x18-x27 registers from the stack.