Chapter 6 Exercises: Architecture

Kyle Swanson

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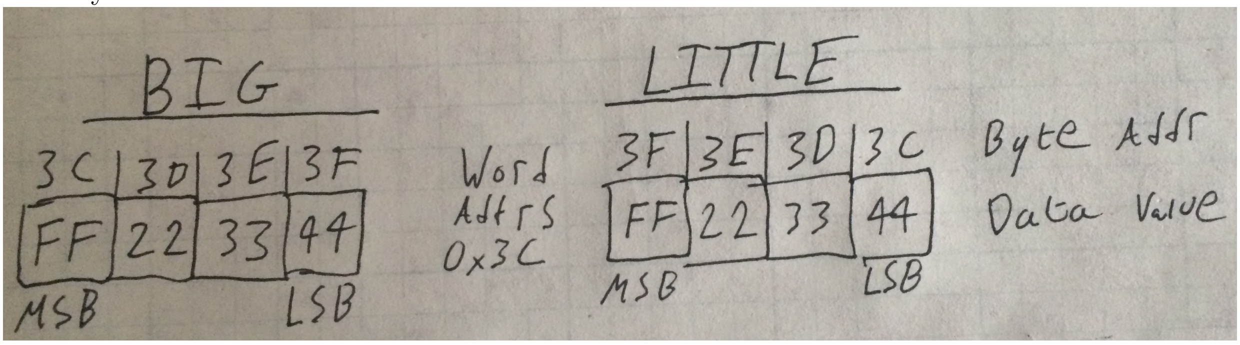
Exercise 6.4 - Repeat Exercise 6.3 for memory storage of a 32-bit word stored at memory word 15 in a byte-addressable memory.
a) What is the byte address of memory word 15?
$15 \times 4 = 15 \times 2^2 = 1111 << 2$
$= 111100 = 0x3C$

b) What are the byte address that memory word 15 spans?
$0x3Cto111100 + 11$
$= 111111 = 0x3F$
$0x3Cto0x3F$

c) Draw the number 0xFF223344 stored at word 15 in both big-endian and little-endian machines. Your drawing should be similar to Figure 6.4. Clearly label the byte address corresponding to each data byte value.



Exercise 6.10 - Convert the following MIPS assembly code into machine language. Write the instructions in hexadecimal.
add $t0, $s0, $s1
This is an R-type instruction. Add
opcode = 000000
rs = $s0 = 16 = 10000
rt = $s1 = 17 = 10001
rd = $t0 = 8 = 01000
shamt = 00000
func = add = 100000

Put it together:
000000 10000 10001 01000 00000 100000
= **0x2114020**

lw $t0, 0x20($t7)
This is a I-type instruction. Load Word - lw rt, imm(rs)

opcode = 100011
rs = $t7 = 15 = 01111
rt = $t0 = 8 = 01000
imm = 0x20 = 0000000000100000

Put it together:
100011 01111 01000 0000000000100000
= **0x8DE80020**

addi \$s0, \$0, -10
This is a I-type instruction. Add Immediate - addi rt, rs, imm

opcode = 001000
rs = 00000
rt = 16 = 10000
imm = -10 = 1111111111110110

Put it together:
001000 00000 10000 1111111111110110
= **0x2010FFF6**

Exercise 6.12 - Consider I-type instructions.
a) Which instructions from Exercise 6.10 are I-type instructions?
addi and lw are both I-type.

b) Sign-extend the 16-bit immediate of each instruction from part (a) so that it becomes a 32bit number.
lw immediate = 0000000000100000
Sign extended = 0000000000000000 0000000000100000 = 0x20
addi immediate = 1111111111110110
Sign extended = 1111111111111111 1111111111110110 = 0xFFFFFFF6

Exercise 6.14 - Do not complete the reverse engineering. Do not explain function. Just convert.

0x20080000 = 001000 00000 01000 0000000000000000
I-type
opcode = 001000 = addi
rs = 00000 = \$0
rt = 01000 = \$t0
imm = 0000000000000000 = 0

addi \$t0, \$0, 0

0x20090001 = 001000 00000 01001 0000000000000001
I-type
opcode = 001000 = addi
rs = 00000 = \$0
rt = 01001 = 9 = \$t1
imm = 0000000000000001 = 1

addi \$t1, \$0, 1

0x0089502A = 000000 00100 01001 01010 00000 101010
R-type
opcode = 000000
rs = 00100 = 4 = \$a0
rt = 01001 = 9 = \$t1
rd = 01010 = 10 = \$t2

shamt = 00000 = 0
func = 101010 = slt

slt $t2, $a0, $t1

0x15400003 = 000101 01010 00000 0000000000000011
I-type
opcode = 000101 = bne
rs = 01010 = 10 = $t2
rt = 00000 = $0
imm = 0000000000000011 = 3 = 0x3

bne $t2, $0, 0x3

0x01094020 = 000000 01000 01001 01000 00000 100000
R-type
opcode = 000000
rs = 01000 = 8 = $t0
rt = 01001 = 9 = $t1
rd = 01000 = 8 = $t0
shamt = 00000 = 0
func = 100000 = add

add $t0, $t0, $t1
0x21290002 = 001000 01001 01001 0000000000000010
I-type
opcode = 001000 = addi
rs = 01001 = 9 = $t1
rt = 01001 = 9 = $t1
imm = 0000000000000010 = 2

addi $t1, $t1, 2

0x08100002 = 000010 00000100000000000000000010
opcode = 000010 = j
label = 00000100000000000000000010 = 0x100002

j 0x100002

0x01001020 = 000000 01000 00000 00010 00000 100000
R-type
opcode = 000000
rs = 01000 = 8 = $t0
rt = 00000 = 0 = $0
rd = 00010 = 2 = $v1
shamt = 00000 = 0
func = 100000 = add

add $v1, $t0, $0

0x03E00008 = 000000 11111 00000 00000 00000 001000
R-type

opcode = 000000
rs = 11111 = 31 = $ra
rt = 00000 = 0 = $0
rd = 00000 = 0 = $0
shamt = 00000 = 0 = $0
func = 001000 = jr

jr $ra

Exercise 6.16 - The nori instruction is not part of the MIPS instruction set, because the same functionality can be implemented using existing functions. Write a short assembly code snippet that has the following functionality: $t0 = $t1 NOR 0xF234. Use as few instructions as possible.

```
li  $t2, -1

ori $t1, $t1, 0xF234
xor $t0, $t1, $t2
```

NORI implemented in Assembler

For my solution, I first set a register to all 1's. I then do the normal OR that was requested. Then I XOR the result with the negative 1's. Which has the effect of negation. Therefore it's a NORI.

ARM Assignment Portion
Please excuse the use of ‘to denote a comment about the assembly code.
It seemed like the most clear/obvious way.
See the comments for descriptions about where the C code is specifically, and how it works.

1 - If

```
int main() {
    int counter = 0;

        if (counter == 1) {
            counter = 10;
        }

    return 0;
}
```

A C language If loop.

```
main:
        0x7a: 0x2000        MOVS      R0, #0
        0x7c: 0x2801        CMP       R0, #1
        ^^ Compare the counter to 1. ^^
        0x7e: 0xd100        BNE.N     ??main_0                 ; 0x82
        ^^ Skip the if, if these are not equal. Branch to ??main_0 ^^
        0x80: 0x200a        MOVS      R0, #10                  ; 0xa
        ^^ if (counter == 1) do this line. ^^
```

```
??main_0:
        0x82: 0x2000        MOVS     R0, #0
        ^^ Put 0 into the return register. ^^
        0x84: 0x4770        BX       LR
```

A Assembler If loop

2 - If Else

```
int main() {
    int counter = 0;

        if (counter == 1) {
                counter = 10;
        } else {
                counter = 20;
        }

    return 0;
}
```

A C language If Else loop.

```
main:
        0x82: 0x2000        MOVS     R0, #0
        0x84: 0x2801        CMP      R0, #1
        ^^ Compare counter to 1. The if statement. ^^
        0x86: 0xd101        BNE.N    0x8c
        ^^ if counter isnt equal to 1. Go to the else. ^^
        0x88: 0x200a        MOVS     R0, #10                ; 0xa
        ^^ Set counter to 10 if it was 1 ^^
        0x8a: 0xe000        B.N      0x8e
        0x8c: 0x2014        MOVS     R0, #20   ; 0x14
        ^^ This is the else portion. ^^
        0x8e: 0x2000        MOVS     R0, #0
        0x90: 0x4770        BX       LR
```

A If Else in Assembler

3 - Switch Case

```
int main() {
    int counter = 0;
    int a = 0;

    while (1) {
        switch (counter) {
                case 0:
                    a = 1;
                    break;
        case 1:
```

```
                a = 2;
            case 2:
                a = 3;
                break;
            default:
                return 0;
        }
        counter++;
    }
}
```

A Switch Case in C Language

```
main:
        0x40: 0x2000        MOVS    R0, #0
        0x42: 0x2100        MOVS    R1, #0
        ^^ Set the counter and a ^^
        0x44: 0xe001        B.N     ??main_0                ; 0x4a
??main_1:
        0x46: 0x2101        MOVS    R1, #1
??main_2:
        0x48: 0x1c40        ADDS    R0, R0, #1
??main_0:
        0x4a: 0x2800        CMP     R0, #0
        ^^ See if counter == 0. The first Case ^^
        0x4c: 0xd0fb        BEQ.N   ??main_1                ; 0x46
        0x4e: 0x2802        CMP     R0, #2
        ^^ see if counter == 2. The case 2. ^^
        0x50: 0xd001        BEQ.N   ??main_3                ; 0x56
        0x52: 0xd202        BCS.N   ??main_4                ; 0x5a
??main_5:
        0x54: 0x2102        MOVS    R1, #2
??main_3:
        0x56: 0x2103        MOVS    R1, #3
        0x58: 0xe7f6        B.N     ??main_2                ; 0x48
??main_4:
        0x5a: 0x2000        MOVS    R0, #0
        0x5c: 0x4770        BX      LRs
```

A Switch Case in Assembler

4 - While

```
int main() {
    int counter = 0;

    while (counter < 10) {
        ++counter;
    }

    return 0;
}
```

A While loop in the C language

```
main:
        0x82: 0x2000          MOVS      R0, #0
        ^^ Set counter to 0 ^^
        0x84: 0xe000          B.N       0x88
        ^^ Skip this next instruction. Go to 0x88 ^^
        0x86: 0x1c40          ADDS      R0, R0, #1
        0x88: 0x280a          CMP       R0, #10                ; 0xa
        ^^ Check if counter == 10 ^^
        0x8a: 0xdbfc          BLT.N     0x86
        ^^ if its less than, go to 0x86. This is the while. ^^
        0x8c: 0x2000          MOVS      R0, #0
        0x8e: 0x4770          BX        LR
```

A While loop in Assembler

5 - For

```c
int main() {
    int counter = 0;

    for (int i=0; i<10; i++) {
        counter++;
    }

    return 0;
}
```

A For Loop in the C Language

```
main:
        0x7a: 0x2000          MOVS      R0, #0
        0x7c: 0x2100          MOVS      R1, #0
        ^^ Set counter and i to 0 ^^
        0x7e: 0xe001          B.N       ??main_0               ; 0x84
??main_1:
        0x80: 0x1c40          ADDS      R0, R0, #1
        0x82: 0x1c49          ADDS      R1, R1, #1
        ^^ Increment both i and counter ^^
??main_0:
        0x84: 0x290a          CMP       R1, #10                ; 0xa
        ^^ Check if i is 10.
        0x86: 0xdbfb          BLT.N     ??main_1               ; 0x80
        ^^ If its less than, go back up. This is the for loop ^^
        0x88: 0x2000          MOVS      R0, #0
        0x8a: 0x4770          BX        LR
```

A For Loop in Assembler

6 - Array

```c
int main() {
    int volatile array[5];

    for (int i=0; i<5; i++) {
        array[i] = i;
    }

    return 0;
}
```

An array in the C language

```
main:
        0x82: 0xb085          SUB       SP, SP, #0x14
        ^^ Allocate the array ^^
        0x84: 0x2000          MOVS      R0, #0
        0x86: 0xe003          B.N       0x90
        0x88: 0xa900          ADD       R1, SP, #0x0
        0x8a: 0xf841 0x0020   STR.W     R0, [R1, R0, LSL #2]
        ^^ Add i into the array ^^
        0x8e: 0x1c40          ADDS      R0, R0, #1
        0x90: 0x2805          CMP       R0, #5
        0x92: 0xdbf9          BLT.N     0x88
        ^^ Same deal, go back up if the loop should go ^^
        0x94: 0x2000          MOVS      R0, #0
        0x96: 0xb005          ADD       SP, SP, #0x14
        ^^ Overwrite the array? ^^
        0x98: 0x4770          BX        LR
```

An array in Assembler

7 - Function Call

```c
int main() {
    int counter = 0;
    int a = 1;
    int b = 2;
    int c = 3;
    int d = 4;
    int e = 5;
    int f = 6;

    while (counter < 5) {
        ++counter;
        int added = sum(counter, a, b, c, d, e, f);
    }

    return 0;
}

int sum(int counter, int a, int b, int c, int d, int e, int f) {
```

```c
    int sum = counter + a + b + c + d + e + f;
    return sum;
}
```

A simple function call in C

```
main:
        0x40: 0xe92d 0x47f0  PUSH.W    {R4-R10, LR}
        0x44: 0xb084         SUB       SP, SP, #0x10
        0x46: 0x2400         MOVS      R4, #0
        0x48: 0x2501         MOVS      R5, #1
        0x4a: 0x2602         MOVS      R6, #2
        0x4c: 0x2703         MOVS      R7, #3
        0x4e: 0xf05f 0x0804  MOVS.W    R8, #4
        0x52: 0xf05f 0x0905  MOVS.W    R9, #5
        0x56: 0xf05f 0x0a06  MOVS.W    R10, #6
        ^^ Allocate the initial data ^^
        0x5a: 0xe00c         B.N       ??main_0                       ; 0x76
??main_1:
        0x5c: 0x1c64         ADDS      R4, R4, #1
        0x5e: 0xf8cd 0xa008  STR.W     R10, [SP, #0x8]
        0x62: 0xf8cd 0x9004  STR.W     R9, [SP, #0x4]
        0x66: 0xf8cd 0x8000  STR.W     R8, [SP]
        0x6a: 0x003b         MOVS      R3, R7
        0x6c: 0x0032         MOVS      R2, R6
        0x6e: 0x0029         MOVS      R1, R5
        0x70: 0x0020         MOVS      R0, R4
        0x72: 0xf000 0xf806  BL        sum                            ; 0x82
        ^^ Go to the sum section. The function call.
??main_0:
        0x76: 0x2c05         CMP       R4, #5
        0x78: 0xdbf0         BLT.N     ??main_1                       ; 0x5c
        ^^ Check the end condition ^^
        0x7a: 0x2000         MOVS      R0, #0
        0x7c: 0xb004         ADD       SP, SP, #0x10
        0x7e: 0xe8bd 0x87f0  POP.W     {R4-R10, PC}
sum:
        0x82: 0x1808         ADDS      R0, R1, R0
        0x84: 0x1810         ADDS      R0, R2, R0
        0x86: 0x1818         ADDS      R0, R3, R0
        0x88: 0x9900         LDR       R1, [SP]
        0x8a: 0x1808         ADDS      R0, R1, R0
        0x8c: 0x9901         LDR       R1, [SP, #0x4]
        0x8e: 0x1808         ADDS      R0, R1, R0
        0x90: 0x9902         LDR       R1, [SP, #0x8]
        0x92: 0x1808         ADDS      R0, R1, R0
        0x94: 0x4770         BX        LR
        ^^ Return to the LR register address ^^
```

A complex function call in Assembler