Policy Reminders

- Include your CS username (a.k.a. NetID) on your page. You will lose a few points from your score if you do not include it.

- You are allowed to work with other students on this homework, as we will not be grading it for correctness. However, each student must turn in their own copy of the homework.

- Show your work for all problems. While we won’t be grading for correctness, you will not receive full credit unless you show your work.
  After all, showing your work is required on the test - and homeworks are intended to help you practice for the test!

Required Problems:

1(e), 2 (various), 3(h-i), 4(h-i), 5(d-e)

Allowable Instructions

When writing MIPS assembly, the only instructions that you are allowed to use (so far) are:

- add, addi, sub, addu, addiu, subu
- beq, bne, j, jal, jr
- slt, slti
- and, andi, or, ori, nor, nori, xor, xori
- sll, srl, sra
- lw, lh, lb, sw, sh, sb
- la
- syscall
- mult, div, mfhi, mflo

While MIPS has many other useful instructions (and the assembler recognizes many pseudo-instructions), do not use them! We want you to learn the fundamentals of how assembly language works - you can use fancy tricks after this class is over.
Problem 1 - Carry Lookahead

For each of the problems below, we have provided two 16-bit numbers. In each problem, calculate the propagate and generate bits; then calculate the super-propagate and super-generate bits for each nibble. Then calculate the carry-in bits for each nibble. Each problem will tell you what value to use for \( c_0 \).

Number your bits from 0 - the least significant bit - to 15 - the most significant.

1(a)  
\[
\begin{align*}
\text{a: } &1001 0111 1000 1011 \\
\text{b: } &1111 0010 0101 0011 \\
\end{align*}
\]

\( c_0 = 0 \)

1(b)  
\[
\begin{align*}
\text{a: } &0111 0101 0000 1101 \\
\text{b: } &1100 0111 0011 0101 \\
\end{align*}
\]

\( c_0 = 1 \)

1(c)  
\[
\begin{align*}
\text{a: } &1110 0111 1100 0001 \\
\text{b: } &0001 1000 0100 1111 \\
\end{align*}
\]

\( c_0 = 1 \)

1(d)  
\[
\begin{align*}
\text{a: } &1110 1010 1100 0101 \\
\text{b: } &0001 0011 0110 1011 \\
\end{align*}
\]

\( c_0 = 0 \)

1(e) - Turn in this one  
\[
\begin{align*}
\text{a: } &0101 0100 1011 0101 \\
\text{b: } &1011 1111 1101 1001 \\
\end{align*}
\]

\( c_0 = 0 \)

Solution:
\( c_0 = 0 \)

Determine the \( p_i \) and \( g_i \) bits first:

\( g_i \) (bit-wise AND): 0001 0100 1001 0001

\( p_i \) (bit-wise OR): 1111 1111 1111 1101

Calculate the \( P_i \) and \( G_i \) bits from the \( p_i \) and \( g_i \) bits:

\[
\begin{align*}
P_0 &= p_3 \cdot p_2 \cdot p_1 \cdot p_0 = 1 \cdot 1 \cdot 0 = 0 \\
P_1 &= p_7 \cdot p_6 \cdot p_5 \cdot p_4 = 1 \cdot 1 \cdot 1 \cdot 1 = 1 \\
P_2 &= p_{11} \cdot p_{10} \cdot p_9 \cdot p_8 = 1 \cdot 1 \cdot 1 \cdot 1 = 1 \\
P_3 &= p_{15} \cdot p_{14} \cdot p_{13} \cdot p_{12} = 1 \cdot 1 \cdot 1 \cdot 1 = 1 \\
\end{align*}
\]

\[
\begin{align*}
G_0 &= g_3 + p_3 \cdot g_2 + p_3 \cdot p_2 \cdot g_1 + p_3 \cdot p_2 \cdot p_1 \cdot g_0 = 0 + 1 + 1 + 1 = 0 \\
G_1 &= g_7 + p_7 \cdot g_6 + p_7 \cdot p_6 \cdot g_5 + p_7 \cdot p_6 \cdot p_5 \cdot g_4 = 1 + 1 + 1 + 1 = 1 \\
G_2 &= g_{11} + p_{11} \cdot g_{10} + p_{11} \cdot p_{10} \cdot g_9 + p_{11} \cdot p_{10} \cdot p_9 \cdot g_8 = 0 + 1 + 1 + 1 = 1 \\
G_3 &= g_{15} + p_{15} \cdot g_{14} + p_{15} \cdot p_{14} \cdot g_{13} + p_{15} \cdot p_{14} \cdot p_{13} \cdot g_{12} = 0 + 1 + 1 + 1 = 1 \\
\end{align*}
\]

\[
\begin{align*}
C_0 &= c_0 = 0 \\
C_1 &= G_0 + P_0 \cdot c_0 = 0 + 0 = 0 \\
C_2 &= G_1 + P_1 \cdot G_0 + P_1 \cdot P_0 \cdot c_0 = 1 + 1 = 1 \\
C_3 &= G_2 + P_2 \cdot G_1 + P_2 \cdot P_1 \cdot G_0 + P_2 \cdot P_1 \cdot P_0 \cdot c_0 = 1 + 1 + 1 + 1 = 1 \\
\end{align*}
\]
Problem 2 - CPU Control Bits

Fill in the table below; give the proper CPU control bits for each of the instructions. Refer to the CPU design, which I’ve included on the last page.

If a given bit is a “don’t care” - meaning that the value of that control bit doesn’t matter, for this instruction, then mark it with an **X**.

Remember: the Result MUX inside the ALU uses the following values:

- 0 - AND
- 1 - OR
- 2 - Add
- 3 - Less

<table>
<thead>
<tr>
<th>Instruction</th>
<th>ALUsrc</th>
<th>aluOp</th>
<th>bInvert</th>
<th>Branch</th>
<th>Jump</th>
<th>MemWrite</th>
<th>MemRead</th>
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<th>RegDst</th>
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Problem 3 - Encoding Instructions

For each of the instructions below, convert it to a 32-bit binary number, and then give the hexadecimal encoding of that binary number.

Check your answers with MARS. But show your work, or you will get no credit.

3(a)  
xor $s4, $t7, $s7

3(b)  
sra $t3, $s1, 19

3(c)  
addi $s0, $s0, -1

3(d)  
j LABEL  
(Assume that the lower 28 bits of the address of LABEL are 8 a4 23 5c.)

NOTE: Don’t worry about checking this one in MARS. I (the instructor) don’t know how to hard-code an address into the j instruction.

3(e)  
sub $s0, $s1, $s2

3(f)  
beq $v0, $zero, LABEL  
(Assume that the immediate field for the branch is 0x1234.)

3(g)  
jr $ra

3(h) - Turn in this one

lb $s3, 100($a0)

Solution: Opcode: 0x20 = 10,0000 in binary  
rs: $a0 is 4, which is 0,0100 in binary.  
rt: $s3 is 19, which is 1,0011 in binary.  
imm: 100_{10} = 64_{16} = 0000,0000,0110,0100 in binary
3(i) - Turn in this one

addi $sp, $sp, -32

Solution: Opcode: 0x08 = 0010 in binary
rs: $sp is 29, which is 0x1d in hex and 1101 in binary.
rt: same as rs
imm: 1111_1111_1110_0000 in binary (remember: −32 = −1 − 31)
Problem 4 - Decoding Instructions

For each 32-bit number below, do the following:

- Convert from hexadecimal to binary. (Actually show the binary bits in your solution.)
- Assuming that the number is a MIPS instruction, decode the instruction.

Appendix A from your textbook will be very handy for this, particularly pages A-24 (list of registers) and A-50 (opcode table). I’ve posted copies of each of these pages on the class website.

I encourage you to use MARS to confirm that you have properly decoded each instruction. Write a simple .s file, which contains your solution; assemble it; confirm that the hex for that instruction matches the original problem. However, you must show your work or you will get no credit.

NOTE: Some of these instructions use registers that you are not (yet) allowed to touch. Don’t worry about it. Just decode it - and then double-check your work in MARS.

4(a)
Hex: 8f ef 40 00

4(b)
Hex: 00 00 00 00

4(c)
Hex: 01 19 80 2b

4(d)
Hex: 02 f8 50 26

4(e)
Hex: 20 44 20 20

4(f)
Hex: 80 38 31 8f

4(g)
Hex: 12 b3 f3 30

4(h) - Turn in this one
Hex: a5 58 3b c9

Solution:
Binary: 1010 0101 0101 1000 0011 1011 1100 1001

**Decode:**

Opcode = 101001 = 10 1001 = 0x29
This opcode is **sh**. This is an I-format instruction:

<table>
<thead>
<tr>
<th>opcode</th>
<th>rs</th>
<th>rt</th>
<th>imm</th>
</tr>
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<tbody>
<tr>
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<td>01</td>
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</tr>
<tr>
<td>1011</td>
<td>1011</td>
<td>1100</td>
<td>1001</td>
</tr>
</tbody>
</table>

rs = 01010 = 10. This is register $t2$.
rt = 11000 = 24. This is register $t8$.
Thus, the instruction is: **sh $t8$, 0x3bc9($t2$)**.

---

4(i) - Turn in this one

Hex: 02 0b 08 23

**Solution:** Binary: 0000 0010 0000 1011 0000 1000 0010 0011

**Decode:**

 Opcode = 000000, which is R-format.
 Func = 10 0011 = 0x23 = 35, which is **subu**.

<table>
<thead>
<tr>
<th>opcode</th>
<th>rs</th>
<th>rt</th>
<th>rd</th>
</tr>
</thead>
<tbody>
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<td>10</td>
<td>01</td>
<td>0000</td>
</tr>
<tr>
<td>0000</td>
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<tr>
<td>0000</td>
<td>1</td>
<td>00</td>
<td>0011</td>
</tr>
<tr>
<td>0000</td>
<td>1</td>
<td>00</td>
<td>1011</td>
</tr>
</tbody>
</table>

rs = 10000 = 16. This is register $s0$.
rt = 01011 = 11. This is register $t3$.
rd = 00001 = 1. This is register $at$. (You will never write instructions that use $at$. But the assembler will generate instructions like that.)

Thus, the instruction is: **subu $at$, $s0$, $t3$**.
Problem 5 - Converting MIPS to C

In the following problems, I will give you a snippet of MIPS assembly, which you will convert to C. Assume that all the MIPS code will use tX registers for temporary values (that is, values which are not given names in C), and that any sX registers represent variables which have names in C.

If the code includes any .data section, then include exactly equivalent C declarations in your code. Also, if the code uses any sX registers, give C declarations for matching variables. The names don’t matter, but giving the proper types is important. The possible types are:

- int - MIPS words. Use this when you don’t know anything else.
- int* - Pointers to MIPS words or arrays of words.
- char* - Pointers to bytes or strings.

To figure out types, you will have to use any number of clues - such as which variables are used in la, lw, sw instructions, how arrays are indexed, or what syscalls are used. Use comments to clearly show what register is associated with each variable name.

Likewise, if the assembly calls a function, give a declaration (not a definition!) for the function, including what you can figure out about the parameters and return type (if any).

Read the examples closely to see what I’m looking for.

5(a)

add $s0, $s1, $s2

5(b)

addi $v0, $zero, 1
add $a0, $s0, $zero
syscall

5(c)

.data
foo:
   .word 1234
bar:
   .word 0

.text
   la $t0, foo
   la $t1, bar
   sw $t0, 0($t1)
5(d) - Turn in this one

.data
foo:
    .word 3

.caseIsImportant:
    .byte 0
    .byte 0
    .byte 0
    .byte 0

.text
    la $s0, foo
    lw $s0, 0($s0)

    la $t1, caseIsImportant
    add $t2, $t1, $s0
    lb $t3, 0($t2)

    addi $v0, $zero, 11
    add $a0, $t3, $zero
    syscall

Solution:

    int foo = 3;
    char caseIsImportant[4];

    printf("%c", caseIsImportant[foo]);

    Instructor's Note: Technically, C sometimes fills in arrays with zeroes, but not always. I'm OK
with you assuming that C will fill it in with zeroes.

    Instructor's Note #2: $s0 is simply a duplicate of the foo in memory. Don't declare a second
variable.

    Instructor's Note #3: Syscall 11 is print character.

5(e) - Turn in this one

    addi $s0, $zero, 100

LOOP:
    slt $t0, $s0, $s7
    bne $t0, $zero, LOOP_END

    addi $v0, $zero, 1
    add $a0, $s0, $zero
    syscall

    addi $v0, $zero, 11  # print_char('\n')
    add $a0, $zero, 0xa
    syscall
addi $s0, $s0, -1
j LOOP

LOOP_END:

Solution:

```c
int i; // s0
int min = ... ; // s7

for (i=100; i>=min; i--)
    printf("%d\n", i);
```
5(f)

beq $s0, $s1, TRUE
bne $s2, $zero, TRUE
j FALSE

TRUE:
add $s3, $zero, $zero
j AFTER_IF

FALSE:
addi $s3, $s3, 1

AFTER_IF:

5(g)

addi $a0, $zero, 123
addi $a1, $zero, 456
jal otherFunc
add $t0, $v0, $zero

addi $v0, $zero, 1
add $a0, $t0, $zero
syscall

5(h)

NOTE: I’d be happy if you remember that bit-masking is the same as modulo-by-power-of-2, and that shifting is the same as division-by-power-of-2. But if you don’t remember that, and write them as bitwise operations, that’s OK too.

.data
MSG: .asciiz "Still a multiple of 4!\n"

.text
LOOP:
andi $t0, $s0, 0x3
bne $t0, $zero, END_LOOP

addi $v0, $zero, 1
la $a0, MSG
syscall

srl $s0, $s0, 2
j LOOP

END_LOOP:
Example: Problem 1(a)

\[ a: \ 1001 \ 0111 \ 1000 \ 1011 \]
\[ b: \ 1111 \ 0010 \ 0101 \ 0011 \]

\[ c_0 = 0 \]

Determine the \( p_i \) and \( g_i \) bits first:

\( g_i \) (bit-wise AND): 1001 0010 0000 0011

\( p_i \) (bit-wise OR): 1111 0111 1101 1011

Calculate the \( P_i \) and \( G_i \) bits from the \( p_i \) and \( g_i \) bits:

\[ P_0 = p_3 \cdot p_2 \cdot p_1 \cdot p_0 = 1 \cdot 0 \cdot 1 \cdot 1 = 0 \]
\[ P_1 = p_7 \cdot p_6 \cdot p_5 \cdot p_4 = 1 \cdot 1 \cdot 0 \cdot 1 = 0 \]
\[ P_2 = p_{11} \cdot p_{10} \cdot p_9 \cdot p_8 = 0 \cdot 1 \cdot 1 \cdot 1 = 0 \]
\[ P_3 = p_{15} \cdot p_{14} \cdot p_{13} \cdot p_{12} = 1 \cdot 1 \cdot 1 \cdot 1 = 1 \]

\[ G_0 = g_3 + p_3 \cdot g_2 + p_3 \cdot p_2 \cdot g_1 + p_3 \cdot p_2 \cdot p_1 \cdot g_0 = 0 + 1 \cdot 0 + 1 \cdot 0 + 1 \cdot 0 \cdot 1 \cdot 1 = 0 \]

\[ G_1 = g_7 + p_7 \cdot g_6 + p_7 \cdot p_6 \cdot g_5 + p_7 \cdot p_6 \cdot p_5 \cdot g_4 = 0 + 1 \cdot 0 + 1 \cdot 1 \cdot 0 + 1 \cdot 1 \cdot 0 \cdot 0 = 0 \]

\[ G_2 = g_{11} + p_{11} \cdot g_{10} + p_{11} \cdot p_{10} \cdot g_9 + p_{11} \cdot p_{10} \cdot p_9 \cdot g_8 = 0 + 0 \cdot 0 + 0 \cdot 1 \cdot 1 + 0 \cdot 1 \cdot 1 \cdot 0 = 0 \]

\[ G_3 = g_{15} + p_{15} \cdot g_{14} + p_{15} \cdot p_{14} \cdot g_{13} + p_{15} \cdot p_{14} \cdot p_{13} \cdot g_{12} = 1 + 1 \cdot 0 + 1 \cdot 1 \cdot 0 + 1 \cdot 1 \cdot 1 \cdot 1 = 1 \]

\[ C_0 = c_0 = 0 \]

\[ C_1 = G_0 + P_0 \cdot c_0 = 0 + 0 \cdot 0 = 0 \]

\[ C_2 = G_1 + P_1 \cdot G_0 + P_1 \cdot P_0 \cdot c_0 = 0 + 0 \cdot 0 + 0 \cdot 0 \cdot 0 = 0 \]

\[ C_3 = G_2 + P_2 \cdot G_1 + P_2 \cdot P_1 \cdot G_0 + P_2 \cdot P_1 \cdot P_0 \cdot c_0 = 0 + 0 \cdot 0 + 0 \cdot 0 \cdot 0 + 0 \cdot 0 \cdot 0 \cdot 0 = 0 \]
Example: Problem 1(b)

\[ a: 0111 \ 0101 \ 0000 \ 1101 \]
\[ b: 1100 \ 0111 \ 0011 \ 0101 \]

\[ c_0 = 1 \]

Determine the \( p_i \) and \( g_i \) bits first:
\[ g_i \text{ (bit-wise AND): } 0100 \ 0111 \ 0011 \ 0101 \]
\[ p_i \text{ (bit-wise OR): } 1111 \ 0111 \ 0011 \ 1101 \]

Calculate the \( P_i \) and \( G_i \) bits from the \( p_i \) and \( g_i \) bits:

\[ P_0 = p_3 \cdot p_2 \cdot p_1 \cdot p_0 = 1 \cdot 1 \cdot 0 \cdot 1 = 0 \]
\[ P_1 = p_7 \cdot p_6 \cdot p_5 \cdot p_4 = 0 \cdot 0 \cdot 1 \cdot 1 = 0 \]
\[ P_2 = p_{11} \cdot p_{10} \cdot p_9 \cdot p_8 = 0 \cdot 1 \cdot 1 \cdot 1 = 0 \]
\[ P_3 = p_{15} \cdot p_{14} \cdot p_{13} \cdot p_{12} = 1 \cdot 1 \cdot 1 \cdot 1 = 1 \]

\[ G_0 = g_3 + p_3 \cdot g_2 + p_3 \cdot p_2 \cdot g_1 + p_3 \cdot p_2 \cdot p_1 \cdot g_0 = 0 + 1 \cdot 1 + 1 \cdot 1 \cdot 0 + 1 \cdot 1 \cdot 0 \cdot 1 = 1 \]
\[ G_1 = g_7 + p_7 \cdot g_6 + p_7 \cdot p_6 \cdot g_5 + p_7 \cdot p_6 \cdot p_5 \cdot g_4 = 0 + 0 \cdot 0 + 0 \cdot 0 + 0 \cdot 0 \cdot 1 \cdot 0 = 0 \]
\[ G_2 = g_{11} + p_{11} \cdot g_{10} + p_{11} \cdot p_{10} \cdot g_9 + p_{11} \cdot p_{10} \cdot p_9 \cdot g_8 = 0 + 0 \cdot 1 + 0 \cdot 1 \cdot 0 + 0 \cdot 1 \cdot 1 \cdot 1 = 0 \]
\[ G_3 = g_{15} + p_{15} \cdot g_{14} + p_{15} \cdot p_{14} \cdot g_{13} + p_{15} \cdot p_{14} \cdot p_{13} \cdot g_{12} = 0 + 1 \cdot 1 + 1 \cdot 1 \cdot 0 + 1 \cdot 1 \cdot 0 = 1 \]

\[ C_0 = c_0 = 1 \]
\[ C_1 = G_0 + P_0 \cdot c_0 = 1 + 0 \cdot 1 = 1 \]
\[ C_2 = G_1 + P_1 \cdot G_0 + P_1 \cdot P_0 \cdot c_0 = 0 + 0 \cdot 1 + 0 \cdot 1 = 0 \]
\[ C_3 = G_2 + P_2 \cdot G_1 + P_2 \cdot P_1 \cdot G_0 + P_2 \cdot P_1 \cdot P_0 \cdot c_0 = 0 + 0 \cdot 0 + 0 \cdot 0 \cdot 1 + 0 \cdot 0 \cdot 0 \cdot 1 = 0 \]
Example: Problem 1(c)

a: 1110 0111 1100 0001
b: 0001 1000 0100 1111

c0 = 1

Determine the \( p_i \) and \( g_i \) bits first:

\( g_i \) (bit-wise AND): 0000 0000 0100 0001

\( p_i \) (bit-wise OR): 1111 1111 1100 1111

Calculate the \( P_i \) and \( G_i \) bits from the \( p_i \) and \( g_i \) bits:

\[
\begin{align*}
P_0 &= p_3 \cdot p_2 \cdot p_1 \cdot p_0 = 1 \cdot 1 \cdot 1 \cdot 1 = 1 \\
P_1 &= p_7 \cdot p_6 \cdot p_5 \cdot p_4 = 1 \cdot 1 \cdot 0 \cdot 0 = 0 \\
P_2 &= p_1 \cdot p_1 \cdot 0 \cdot p_9 \cdot p_8 = 1 \cdot 1 \cdot 1 \cdot 1 = 1 \\
P_3 &= p_5 \cdot p_1 \cdot 4 \cdot p_1 \cdot 3 \cdot p_1 \cdot 2 = 1 \cdot 1 \cdot 1 \cdot 1 = 1 \\
G_0 &= g_3 + p_3 \cdot g_2 + p_3 \cdot p_2 \cdot g_1 + p_3 \cdot p_2 \cdot p_1 \cdot g_0 = 0 + 1 \cdot 0 + 1 \cdot 1 \cdot 0 + 1 \cdot 1 \cdot 1 = 1 \\
G_1 &= g_7 + p_7 \cdot g_6 + p_7 \cdot p_6 \cdot g_5 + p_7 \cdot p_6 \cdot p_5 \cdot g_4 = 0 + 1 \cdot 1 + 1 \cdot 1 \cdot 0 + 1 \cdot 1 \cdot 0 = 1 \\
G_2 &= g_1 \cdot 1 + p_1 \cdot 1 \cdot g_1 \cdot 0 + p_1 \cdot 1 \cdot p_1 \cdot 0 \cdot g_9 + p_1 \cdot 1 \cdot p_1 \cdot 0 \cdot p_9 \cdot g_8 = 0 + 1 \cdot 0 + 1 \cdot 0 + 1 \cdot 1 \cdot 0 = 0 \\
G_3 &= g_1 \cdot 5 + p_1 \cdot 5 \cdot g_1 \cdot 4 + p_1 \cdot 5 \cdot p_1 \cdot 4 \cdot g_1 \cdot 3 + p_1 \cdot 5 \cdot p_1 \cdot 4 \cdot p_1 \cdot 3 \cdot g_1 \cdot 2 = 0 + 1 \cdot 0 + 1 \cdot 0 + 1 \cdot 1 \cdot 0 = 0
\end{align*}
\]

\( C_0 = c_0 = 1 \)

\( C_1 = G_0 + P_0 \cdot c_0 = 1 + 1 \cdot 1 = 1 \)

\( C_2 = G_1 + P_1 \cdot G_0 + P_1 \cdot P_0 \cdot c_0 = 1 + 0 \cdot 1 + 0 \cdot 1 = 1 \)

\( C_3 = G_2 + P_2 \cdot G_1 + P_2 \cdot P_1 \cdot G_0 + P_2 \cdot P_1 \cdot P_0 \cdot c_0 = 0 + 1 \cdot 1 + 1 \cdot 0 + 1 \cdot 0 \cdot 1 = 1 \)
Example: Problem 1(d)

\(c_0 = 0\)

Determine the \(p_i\) and \(g_i\) bits first:

\(g_i\) (bit-wise AND): 0000 0010 0100 0001

\(p_i\) (bit-wise OR): 1111 1011 1110 1111

Calculate the \(P_i\) and \(G_i\) bits from the \(p_i\) and \(g_i\) bits:

\[P_0 = p_3 \cdot p_2 \cdot p_1 \cdot p_0 = 1 \cdot 1 \cdot 1 \cdot 1 = 1\]

\[P_1 = p_7 \cdot p_6 \cdot p_5 \cdot p_4 = 1 \cdot 1 \cdot 1 \cdot 0 = 0\]

\[P_2 = p_{11} \cdot p_{10} \cdot p_9 \cdot p_8 = 1 \cdot 0 \cdot 1 \cdot 1 = 0\]

\[P_3 = p_{15} \cdot p_{14} \cdot p_{13} \cdot p_{12} = 1 \cdot 1 \cdot 1 \cdot 1 = 1\]

\[G_0 = g_3 + p_3 \cdot g_2 + p_3 \cdot p_2 \cdot g_1 + p_3 \cdot p_2 \cdot p_1 \cdot g_0 = 0 + 1 \cdot 0 + 1 \cdot 1 \cdot 1 = 1\]

\[G_1 = g_7 + p_7 \cdot g_6 + p_7 \cdot p_6 \cdot g_5 + p_7 \cdot p_6 \cdot p_5 \cdot g_4 = 0 + 1 \cdot 1 + 1 \cdot 1 \cdot 0 = 0\]

\[G_2 = g_{11} + p_{11} \cdot g_{10} + p_{11} \cdot p_{10} \cdot g_9 + p_{11} \cdot p_{10} \cdot p_9 \cdot g_8 = 0 + 1 \cdot 0 + 1 \cdot 1 \cdot 1 = 0\]

\[G_3 = g_{15} + p_{15} \cdot g_{14} + p_{15} \cdot p_{14} \cdot g_{13} + p_{15} \cdot p_{14} \cdot p_{13} \cdot g_{12} = 0 + 1 \cdot 1 + 1 \cdot 1 \cdot 0 = 0\]

\[C_0 = c_0 = 0\]

\[C_1 = G_0 + P_0 \cdot c_0 = 1 + 1 \cdot 0 = 1\]

\[C_2 = G_1 + P_1 \cdot G_0 + P_1 \cdot P_0 \cdot c_0 = 1 + 0 \cdot 1 + 0 \cdot 1 = 1\]

\[C_3 = G_2 + P_2 \cdot G_1 + P_2 \cdot P_1 \cdot G_0 + P_2 \cdot P_1 \cdot P_0 \cdot c_0 = 0 + 0 \cdot 1 + 0 \cdot 1 + 0 \cdot 1 = 0\]
Example: Problem 3(a)

xor $s4, $t7, $s7
 Opcode: 00_0000 in binary
 Funct: 38=0x26 = 10_0110 in binary
 rd: $s4 is 20=0x14, which is 1_0100 in binary.
 rs: $t7 is 15=0x0f, which is 0_1111 in binary.
 rt: $s7 is 23=0x17, which is 1_0111 in binary.

<table>
<thead>
<tr>
<th>opcode</th>
<th>0000 00</th>
</tr>
</thead>
<tbody>
<tr>
<td>rs</td>
<td>01 111</td>
</tr>
<tr>
<td>rt</td>
<td>1 0111</td>
</tr>
<tr>
<td>rd</td>
<td>1010 0</td>
</tr>
<tr>
<td>shamt</td>
<td>000 00</td>
</tr>
<tr>
<td>funct</td>
<td>10 0110</td>
</tr>
</tbody>
</table>

0000 0001 1111 0111 1010 0000 0010 0110

Hex: 01 f7 a0 26

Example: Problem 3(b)

sra $t3, $s1, 19
 Opcode: 00_0000 in binary
 Funct: 3 = 00_0011 in binary
 rd: $t3 is 11=0x0b, which is 0_1011 in binary.
 rt: $s1 is 17=0x11, which is 1_0001 in binary.
 rs: 0 in all shift instructions (see page A-56)
 shamt: 19=0x13 = 1_0011 in binary

<table>
<thead>
<tr>
<th>opcode</th>
<th>0000 00</th>
</tr>
</thead>
<tbody>
<tr>
<td>rs</td>
<td>00 000</td>
</tr>
<tr>
<td>rt</td>
<td>1 0001</td>
</tr>
<tr>
<td>rd</td>
<td>0101 1</td>
</tr>
<tr>
<td>shamt</td>
<td>100 11</td>
</tr>
<tr>
<td>funct</td>
<td>00 0011</td>
</tr>
</tbody>
</table>

0000 0000 0001 0001 0101 1100 1100 0011

Hex: 00 11 5c c3
Example: Problem 3(c)

addi $s0, $s0, -1

Opcode: 0x08 = 001000 in binary
rt: $s0 is 16=0x10, which is 10000 in binary.
rs: same as rt
imm: 1111111111111111 in binary

<table>
<thead>
<tr>
<th>opcode</th>
<th>0010 00</th>
</tr>
</thead>
<tbody>
<tr>
<td>rs</td>
<td>10 000</td>
</tr>
<tr>
<td>rt</td>
<td>1 0000</td>
</tr>
<tr>
<td>imm</td>
<td>1111 1111 1111 1111</td>
</tr>
</tbody>
</table>

0010 0010 0001 0000 1111 1111 1111 1111

Hex: 22 10 ff ff

Example: Problem 3(d)

j 0x8_a4_23_5c

Opcode: 0x02 = 000010 in binary
J field:

- Start with the 28 bit hex value: 8 a4 23 5c
- Convert to binary 1000 1010 0100 0010 0011 0101 1100
- Drop the last two bits: 1000 1010 0100 0010 0011 0101 11
- Reorganize into nibbles: 10 0010 1001 0000 1000 1101 0111

<table>
<thead>
<tr>
<th>opcode</th>
<th>0000 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-field</td>
<td>10 0010 1001 0000 1000 1101 0111</td>
</tr>
</tbody>
</table>

0000 1010 0010 1001 0000 1000 1101 0111

Hex: 0a 29 08 d7
Example: Problem 3(e)

\[ \text{sub } $s0, $s1, $s2 \]

 Opcode: 00_0000 in binary
 Funct: 34 = 0x22 = 10_0010 in binary
 rd: $s0 is 16=0x10, which is 1_0000 in binary.
 rs: $s1 is 17=0x11, which is 1_0001 in binary.
 rt: $s2 is 18=0x12, which is 1_0010 in binary.

\[
\begin{array}{lllllllll}
\text{opcode} & 0000 & 00 \\
\text{rs} & 10 & 001 \\
\text{rt} & 1 & 0010 \\
\text{rd} & 1000 & 0 \\
\text{shamt} & 000 & 00 \\
\text{funct} & 10 & 0010 \\
\end{array}
\]

Hex: 02 32 80 22

Example: Problem 3(f)

\[ \text{beq } $v0, $zero, LABEL \]

(Assume that the immediate field for the branch is 0x1234.)

 Opcode: 0x04 = 00_0100 in binary
 rs: $v0 is 2, which is 0_0010 in binary.
 rt: $zero is 0_0000 in binary.
 imm: 0001_0010_0011_0100 in binary

\[
\begin{array}{lllllllll}
\text{opcode} & 0001 & 00 \\
\text{rs} & 00 & 010 \\
\text{rt} & 0 & 0000 \\
\text{imm} & 0001 & 0010 & 0011 & 0100 \\
\end{array}
\]

Hex: 10 40 12 34
Example: Problem 3(g)

`jr $ra`

Opcode: 00,0000 in binary
Funct: 8 = 0x08 = 00,1000 in binary
I looked at page A-64 to confirm that `jr` uses `rs` to encode the jump register, and uses 0 for `rt`, `rd`.
rd: 0
rs: `$ra` is 31, which is 1,1111 in binary.
rt: 0

<table>
<thead>
<tr>
<th>Field</th>
<th>Binary Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>opcode</td>
<td>0000 00</td>
</tr>
<tr>
<td>rs</td>
<td>11 111</td>
</tr>
<tr>
<td>rt</td>
<td>0 0000</td>
</tr>
<tr>
<td>rd</td>
<td>0000 0</td>
</tr>
<tr>
<td>shamt</td>
<td>000 00</td>
</tr>
<tr>
<td>funct</td>
<td>00 1000</td>
</tr>
</tbody>
</table>

Hex: 03 e0 00 08
Example: Problem 4(a)

Hex: 8f ef 40 00

Binary: 1000 1111 1110 1111 0100 0000 0000 0000

Decode:
Opcode = 100011 = 10 0011 = 0x23.
This opcode is lw. This is an I-format instruction:

1000 1111 1110 1111 0100 0000 0000 0000
opcode 1000 11
rs 11 111
rt 0 1111
imm 0100 0000 0000 0000

rs = 11111 = 31. This is register $ra.
rt = 01111 = 15. This is register $t7.

NOTE: You are not required to convert the immediate field to decimal; let’s not bother with it here.
Which register is rs and which is rt? To find that out, I looked at the details for the lw instruction on page A-67 of the appendix, where I found this:

lw rt, address

So rt is the register on the left!
Thus, the instruction is: lw $t7, 0x4000($ra)

Example: Problem 4(b)

Hex: 00 00 00 00

Binary: 0000 0000 0000 0000 0000 0000 0000 0000

Decode:
Opcode = 000000 = 00 0000 = 0x00
This opcode is used for lots of R-format instructions; we need to look at the funct field as well.
Funct = 000000 = 0x00
This opcode/funct combination is sll.

Obviously, all of the fields in the instruction are zero - so all three of the registers are 00000, which is $zero. Likewise, the shift value is 0. So the instruction is:

sll $zero, $zero, 0

Instructor’s Note: This is a NOP instruction (no-operation). Most architectures have one (or more) instructions designed to “do nothing for one cycle.” In MIPS, it’s not a special opcode - it’s just a shift instruction which happens to accomplish nothing!
Example: Problem 4(c)

Hex: 01 19 80 2b
Binary: 0000 0001 0001 1001 1000 0000 0010 1011

Decode:
 Opcode = 0000 00 = 0x00
 This is an R-format instruction; we need to look at the funct field.
 Funct = 101011 = 0x2b = 43 decimal
 00/43 is sltu. You can find this on page A-50; I confirmed this by looking at page A-58 of Appendix A.

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>opcode</td>
<td>0000 00</td>
</tr>
<tr>
<td>rs</td>
<td>01 000</td>
</tr>
<tr>
<td>rt</td>
<td>1 1001</td>
</tr>
<tr>
<td>rd</td>
<td>1000 0</td>
</tr>
<tr>
<td>shamt</td>
<td>000 00</td>
</tr>
<tr>
<td>funct</td>
<td>10 1011</td>
</tr>
</tbody>
</table>

rs = 01000 = 8. This is $t0
rt = 11001 = 25. This is $t9
rd = 10000 = 16. This is $s0
Thus, the instruction is sltu $s0, $t0, $t9

Example: Problem 4(d)

Hex: 02 f8 50 26
Binary: 0000 0010 1111 1000 0101 0000 0010 0110

Decode:
 Opcode = 000000 = 0x00
 This is an R-format instruction; we need to look at the funct field.
 Funct = 10 0110 = 0x26 = 38 decimal
 00/38 is xor. You can find this on page A-50; I confirmed this by looking at page A-57 of Appendix A.

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>opcode</td>
<td>0000 00</td>
</tr>
<tr>
<td>rs</td>
<td>10 111</td>
</tr>
<tr>
<td>rt</td>
<td>1 1000</td>
</tr>
<tr>
<td>rd</td>
<td>0101 0</td>
</tr>
<tr>
<td>shamt</td>
<td>000 00</td>
</tr>
<tr>
<td>funct</td>
<td>10 0110</td>
</tr>
</tbody>
</table>

rs = 10111 = 23. This is $s7
rt = 11000 = 24. This is $t8
rd = 01010 = 10. This is $t2
Thus, the instruction is xor $t2, $s7, $t8
Example: Problem 4(e)

Hex: 20 44 20 20
Binary: 0010 0000 0100 0100 0010 0000 0010 0000

Decode:
Opcode = 001000 = 00 1000 = 0x08.
This opcode is addi. This is an I-format instruction:

\[
\begin{align*}
\text{opcode} & : 0010 00 \\
\text{rs} & : 00 010 \\
\text{rt} & : 0 0100 \\
\text{imm} & : 0010 0000 0010 0000
\end{align*}
\]

rs = 00010 = 2. This is register $v0.$
rt = 00100 = 4. This is register $a0.$
Thus, the instruction is: \text{addi } a0, v0, 0x2020.

Example: Problem 4(f)

Hex: 80 38 31 8f
Binary: 1000 0000 0011 1000 0011 0001 1000 1111

Decode:
Opcode = 100000 = 10 0000 = 0x20
This opcode is lb. This is an I-format instruction:

\[
\begin{align*}
\text{opcode} & : 1000 00 \\
\text{rs} & : 00 001 \\
\text{rt} & : 1 1000 \\
\text{imm} & : 0011 0001 1000 1111
\end{align*}
\]

rs = 00001 = 1. This is register $at$.
(rt would be very strange to use $at$ as the base register for a load, the hardware still has to support it!)
rt = 11000 = 24. This is register $t8$.
Thus, the instruction is: \text{lb } t8, 0x318f(at).
Example: Problem 4(g)

Hex: 12 b3 f3 30

Binary: 0001 0010 1011 0011 1111 0011 0011 0000

Decode:
Opcode = 000100 = 00 0100 = 0x04.
This opcode is `beq`. This is an I-format instruction:

<table>
<thead>
<tr>
<th>opcode</th>
<th>0001 00</th>
</tr>
</thead>
<tbody>
<tr>
<td>rs</td>
<td>10 101</td>
</tr>
<tr>
<td>rt</td>
<td>1 0011</td>
</tr>
<tr>
<td>imm</td>
<td>1111 0011 0011 0000</td>
</tr>
</tbody>
</table>

rs = 10101 = 21. This is register $s5$.
rt = 10011 = 19. This is register $s3$.

**NOTE:** You are not required to convert the immediate field to decimal; let’s not bother with it here.
Thus, the instruction is: beq $s5$, $s3$, 0xf330 (we’re assuming here that there is some label at PC+4+0xf330.)
Example: Problem 5(a)

Instructor’s Note: This uses three \texttt{sX} registers. None of them have any names already, so we’ll name them all. We don’t have any clues about their types, so we’ll just assume that they are \texttt{int}. However, this explanation is not needed in your answer. All you need is the solution below:

```
int bar = ... ; // s1
int baz = ... ; // s2
int foo; // s0
foo = bar+baz;
```

Instructor’s Note #2: It’s a good idea to use the \texttt{=} ... ; to show that a variable has a value (but that you don’t know what it is). That isn’t necessary for \texttt{foo}, though, because you don’t care what its previous value was - you’re about to overwrite it.

Example: Problem 5(b)

```
int foo = ... ; // s0
printf("%d", foo);
```

Instructor’s Note: Note that the \texttt{printf()} doesn’t include a newline, because the MIPS code doesn’t print out a newline. Do not add things which you think \textbf{ought} to be in the code - just translate what is actually there!

Example: Problem 5(c)

```
int foo = 1234;
int *bar = NULL;
bar = &foo;
```

Instructor’s Note: We take the address of \texttt{foo}, and store it into memory location \texttt{bar}. Thus, \texttt{bar} is a pointer to \texttt{foo}.

Example: Problem 5(f)

```
int foo = ... ; // s0
int bar = ... ; // s1
int baz = ... ; // s2
int thing = ... ; // s3

if (foo == bar || baz != 0)
    thing = 0;
else
    thing++;
```
Example: Problem 5(g)

    int otherFunc(int, int);

    printf("%d", otherFunc(123, 456));

Example: Problem 5(h)

    int x = ... ;    // s0

    while (x % 4 == 0)
    {
        printf("Still a multiple of 4!\n");
        x /= 4;
    }