Problem 1 - A simple loop in MIPS

Recall that the factorial, $n!$, of $n$ is given as follows:

\[
0! = 1 \\
n! = n \cdot (n - 1)! \quad n > 0
\]

Write a MIPS program which takes a non-negative integer $n$ in $\$1$ and stores $n!$ in $\$3$.

Solution:

;Initialize the answer ($\$3$) = 1 and $\$11$ = 1
lis $\$3$
.word 1
add $\$11$, $\$3$, $0$

;Loop until $\$1 = 0
loop: beq $\$1$, $0$, end

; $\$3$ = $\$3$ * $\$1$
mult $\$3$, $\$1$
mflo $\$3$

;Go to next index ($\$1 = \$1 - 1$)
sub $\$1$, $\$1$, $\$11$
beq $\$0$, $0$, loop

end: jr $\$31$
Problem 2 - More loops in MIPS

Recall that the Fibonacci sequence can be defined as follows:

\[ f_0 = 0 \]
\[ f_1 = 1 \]
\[ f_{n+2} = f_{n+1} + f_n \]

Write a MIPS program which takes a non-negative integer \( n \) in \$1\ and stores \( f_n \) in \$3. Solution:

```mips
; \$3 = f_i, \$4 = f_{i+1}
; \$11 = 1
add $3, $0, $0
lis $4
.word 1
add $11, $4, $0

;Loop until \$1 = 0
loop: beq $1, $0, end

;\$5 = f_{i+1}
add $5, $4, $0
;\$4 = f_{i+2} = f_i + f_{i+1}
add $4, $3, $4
;\$3 = f_{i+1}
add $3, $5, $0

;Go to the next iteration (\$1 = \$1 - 1)
sub $1, $1, $11
beq $0, $0, loop

end: jr $31
```
Problem 3 - Arrays in MIPS

Thus far we’ve only written programs which accept two integers as arguments, but with cs241-array we can also write programs which manipulate arrays. Write a MIPS program which accepts the address of an array in $1$ and its length in $2$ and stores the product of the numbers in the array in $3$.

Solution:

```
    ;$2 = 4 * $2 + $1
    add $2, $2, $2
    add $2, $2, $2
    add $2, $2, $1

    lis $4
    .word 4

    lis $3
    .word 1

    ;Loop until $1 = $2, incrementing $1 by 4 every time
    loop: beq $1, $2, end

    ;$5 = $1 = A[i]
    lw $5, 0($1)

    ;$3 = $3 * $5
    mult $3, $5
    mflo $3

    ;Go to next index
    add $1, $1, $4
    beq $0, $0, loop

    end: jr $31
```
Problem 4 - Basic I/O in MIPS

Recall that you can read from stdin and write to stdout by loading from or storing to addresses 0xffff0004 and 0xffff000c respectively. Note that EOF is represented by −1, and otherwise a single byte will be read or written at a time.

Write a MIPS program which reads in two characters from stdin (you may assume EOF is not encountered) and prints out the character 1 if the first is less than the second, or 0 otherwise. It should then print a newline.

Solution:

```
; $27 is stdin, $28 is stdout
lis $27
.word 0xffff0004
lis $28
.word 0xffff000c

;$20 is the '0' character
lis $20
.word 48 ;0x30 in hex

; Load characters from stdin
lw $3, 0($27)
lw $4, 0($27)

; $3 = 1 if $3 < $4, 0 otherwise
slt $3, $3, $4

; Note that '0' + 0 = '0' and '0' + 1 = '1'
add $20, $20, $3

; Print the character to stdout
sw $20, 0($28)

; Newline is 10 = 0xA, so load and print it
lis $20
.word 10
sw $20, 0($28)

jr $31
```
Problem 5 - I/O and loops in MIPS

Adapt your solution to problem 4 to read in characters from stdin until EOF is encountered and print out their uppercase versions to stdout. If the character is not a lower-case letter, simply print out the character unchanged.

Solution:

; $27 is stdin, $28 is stdout
lis $27
.word 0xffff0004
lis $28
.word 0xffff000c

;$25 = 'a', the first lowercase letter.
; Characters less than $25 are not lowercase.
lis $25
.word 97

;$26 = 'z', the last lowercase letter.
; Characters more than $26 are not lowercase.
lis $26
.word 122

;$20 is 'A' - 'a', the amount that
; we should add to make a character uppercase
lis $20
.word -32

;$24 is EOF
lis $24
.word -1

; Load characters until EOF is encountered
loop: lw $3, 0($27)
beq $3, $24, end

; If $3 < $25, we can print this unchanged
slt $5, $3, $25
bne $5, $0, print

; If $26 < $3, we can print this unchanged
slt $5, $26, $3
bne $5, $0, print
; We are lowercase, add $20
add $3, $3, $20

print:  sw $3, 0($28)
beq $0, $0, loop

end:  jr $31
Problem 6 - Using the stack in MIPS

Write a MIPS program which reads in characters from stdin until EOF is encountered, then prints the same characters out backwards to stdout. Use the stack to store the characters.

Solution:

; $27 is stdin, $28 is stdout
lis $27
.word 0xffff0004
lis $28
.word 0xffff000c

;$24 is EOF
lis $24
.word -1

;$4 is 4
lis $4
.word 4

;$26 is the initial value of $30
add $26, $30, $0

; Load characters until EOF is encountered
loop: lw $3, 0($27)
beq $3, $24, end

; Push the character
sw $3, -4($30)
sub $30, $30, $4

; Repeat
beq $0, $0, loop

end:

; Pop characters until $30 is back where it started
loop2: beq $26, $30, end2

; Pop a character
add $30, $30, $4
lw $3, -4($30)
; Print the character
sw $3, 0($28)

; Repeat
beq $0, $0, loop2

end2:    jr $31
Problem 7 - Functions and recursion in MIPS

Rewrite your solution to Problem 1 using a recursive function instead of a loop.

Solution:

;The first instance of fact is implicitly called by the start of the program

fact:    sw $31, -4($30)
         sw $1,  -8($30)
         sw $11, -12($30)
         lis $31
         .word 12
         sub $30, $30, $31

         lis $11
         .word 1

;If $1 = 0, base case of $3 = 1
         bne $1, $0, recur
         add $3, $11, $0
         beq $0, $0, clean

;Call fact with $1 - 1
recur:  sub $1, $1, $11
         lis $31
         .word fact
         jalr $31

;Restore value of $1
         add $1, $1, $11

;Multiply previous answer by $1 to get new factorial
         mult $3, $1
         mflo $3

clean: lis $31
       .word 12
       add $30, $30, $31

       lw $11, -12($30)
       lw $1,  -8($30)
       lw $31, -4($30)
       jr $31