Lecture 7: Examples, MARS

• Today’s topics:
  - More examples
  - MARS intro
Example 2 (pg. 101)

```c
int fact (int n)
{
    if (n < 1) return (1);
    else return (n * fact(n-1));
}
```

Notes:
The caller saves $a0 and $ra in its stack space.
Temp register $t0 is never saved.
slti

if ($a0 < 1)
then ...
else ...

Easier to implement with pseudo-instructions like blt, bge.

slti $t0, $a0, 1    # if $a0 < 1, set $t0 = 1, else $t0 = 0
beq $t0, $zero, else then:

    ...

else:
Dealing with Characters

• Instructions are also provided to deal with byte-sized and half-word quantities: lb (load-byte), sb, lh, sh

• These data types are most useful when dealing with characters, pixel values, etc.

• C employs ASCII formats to represent characters – each character is represented with 8 bits and a string ends in the null character (corresponding to the 8-bit number 0); A is 65, a is 97
Example 3 (pg. 108)

Convert to assembly:
void strcpy (char x[], char y[])
{
    int i;
    i=0;
    while ((x[i] = y[i]) != '\0')
        i += 1;
}

Notes:
Temp registers not saved.

strcpy:
addi $sp, $sp, -4
sw $s0, 0($sp)
add $s0, $zero, $zero
L1: add $t1, $s0, $a1
lb $t2, 0($t1)
add $t3, $s0, $a0
sb $t2, 0($t3)
beq $t2, $zero, L2
addi $s0, $s0, 1
j L1
L2: lw $s0, 0($sp)
addi $sp, $sp, 4
jr $ra
Saving Conventions

• Caller saved: Temp registers $t0-$t9 (the callee won’t bother saving these, so save them if you care), $ra (it’s about to get over-written), $a0-$a3 (so you can put in new arguments), $fp (if being used by the caller)

• Callee saved: $s0-$s7 (these typically contain “valuable” data)

• Read the Notes on the class webpage on this topic
Large Constants

- Immediate instructions can only specify 16-bit constants.

- The lui instruction is used to store a 16-bit constant into the upper 16 bits of a register... combine this with an OR instruction to specify a 32-bit constant.

- The destination PC-address in a conditional branch is specified as a 16-bit constant, relative to the current PC.

- A jump (j) instruction can specify a 26-bit constant; if more bits are required, the jump-register (jr) instruction is used.

- See green sheet!
Starting a Program

C Program (x.c)

Compiler

Assembly language program (x.s)

Assembler

Object: machine language module (x.o)

Assembler

Object: library routine (machine language (x.a, x.so)

Linker

Executable: machine language program (a.out)

Linker

Loader

Memory
Role ofAssembler

• Convert pseudo-instructions into actual hardware instructions – pseudo-instrs make it easier to program in assembly – examples: “move”, “blt”, 32-bit immediate operands, labels, etc.

• Convert assembly instrs into machine instrs – a separate object file (x.o) is created for each C file (x.c) – compute the actual values for instruction labels – maintain info on external references and debugging information
Role of Linker

• Stitches different object files into a single executable
  ▪ patch internal and external references
  ▪ determine addresses of data and instruction labels
  ▪ organize code and data modules in memory

• Some libraries (DLLs) are dynamically linked – the executable points to dummy routines – these dummy routines call the dynamic linker-loader so they can update the executable to jump to the correct routine
void sort (int v[ ], int n) 
{ 
    int i, j;
    for (i=0; i<n; i+=1) { 
        for (j=i-1; j>=0 && v[j] > v[j+1]; j-=1) { 
            swap (v,j);
        }
    }
}

void swap (int v[ ], int k) 
{ 
    int temp;
    temp = v[k];
    v[k] = v[k+1];
    v[k+1] = temp;
}

• Allocate registers to program variables
• Produce code for the program body
• Preserve registers across procedure invocations
The swap Procedure

- Register allocation: $a0 and $a1 for the two arguments, $t0 for the temp variable – no need for saves and restores as we’re not using $s0-$s7 and this is a leaf procedure (won’t need to re-use $a0 and $a1)

```assembly
swap:    sll     $t1, $a1, 2
         add    $t1, $a0, $t1
         lw      $t0, 0($t1)
         lw      $t2, 4($t1)
         sw      $t2, 0($t1)
         sw      $t0, 4($t1)
         jr      $ra
```
The sort Procedure

- Register allocation: arguments v and n use $a0 and $a1, i and j use $s0 and $s1; must save $a0 and $a1 before calling the leaf procedure

- The outer for loop looks like this: (note the use of pseudo-instrs)

  ```
  move $s0, $zero     # initialize the loop
  loopbody1: bge $s0, $a1, exit1    # will eventually use slt and beq
  ... body of inner loop ...
  addi $s0, $s0, 1
  j loopbody1
  exit1:
  ```

```c
for (i=0; i<n; i+=1) {
    for (j=i-1; j>=0 && v[j] > v[j+1]; j-=1) {
        swap (v,j);
    }
}
```
The sort Procedure

• The inner for loop looks like this:

    addi  $s1, $s0, -1  # initialize the loop
loopbody2: blt     $s1, $zero, exit2  # will eventually use slt and beq
    sll      $t1,  $s1, 2
    add      $t2, $a0, $t1
    lw       $t3, 0($t2)
    lw       $t4, 4($t2)
    ble      $t3, $t4, exit2
... body of inner loop ...
    addi     $s1, $s1, -1
    j            loopbody2

exit2:

for (i=0; i<n; i+=1) {
    for (j=i-1; j>=0 && v[j] > v[j+1]; j-=1) {
        swap (v,j);
    }
}
Saves and Restores

- Since we repeatedly call “swap” with $a0 and $a1, we begin “sort” by copying its arguments into $s2 and $s3 – must update the rest of the code in “sort” to use $s2 and $s3 instead of $a0 and $a1

- Must save $ra at the start of “sort” because it will get over-written when we call “swap”

- Must also save $s0-$s3 so we don’t overwrite something that belongs to the procedure that called “sort”
Saves and Restores

sort:    addi     $sp, $sp, -20
sw       $ra, 16($sp)
sw       $s3, 12($sp)
sw       $s2, 8($sp)
sw       $s1, 4($sp)
sw       $s0, 0($sp)
move    $s2, $a0
move    $s3, $a1
...    move    $a0, $s2     # the inner loop body starts here
move    $a1, $s1
jal         swap
...    exit1:  lw         $s0, 0($sp)
...    addi       $sp, $sp, 20
jr            $ra
MARS

- MARS is a simulator that reads in an assembly program and models its behavior on a MIPS processor.

- Note that a “MIPS add instruction” will eventually be converted to an add instruction for the host computer’s architecture – this translation happens under the hood.

- To simplify the programmer’s task, it accepts pseudo-instructions, large constants, constants in decimal/hex formats, labels, etc.

- The simulator allows us to inspect register/memory values to confirm that our program is behaving correctly.
MARS Intro

- Directives, labels, global pointers, system calls
MARS Intro
MARS Intro

• Read the google doc on the class webpage for details!

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<thead>
<tr>
<th>Registers</th>
<th>Coproc 1</th>
<th>Coproc 0</th>
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<td>Value</td>
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</tr>
<tr>
<td>$s2</td>
<td>18</td>
<td>0x00000000</td>
</tr>
</tbody>
</table>
Example Print Routine

.data
  str: .asciiz "the answer is "

.text
  li $v0, 4               # load immediate; 4 is the code for print_string
  la $a0, str            # the print_string syscall expects the string
  syscall                # to load the address of the operand (str)

  syscall                # MARS will now invoke syscall-4
  li $v0, 1              # syscall-1 corresponds to print_int
  li $a0, 5              # print_int expects the integer as its argument
  syscall                # MARS will now invoke syscall-1
Example

- Write an assembly program to prompt the user for two numbers and print the sum of the two numbers
Example

.data
str1: .asciiz "Enter 2 numbers:"
str2: .asciiz "The sum is"

.text
li $v0, 4
la $a0, str1
syscall
li $v0, 5
syscall
add $t0, $v0, $zero
li $v0, 5
syscall
add $t1, $v0, $zero
li $v0, 4
la $a0, str2
syscall
li $v0, 1
add $a0, $t1, $t0
syscall