CSCI 210: Computer Organization
Lecture 11: Control Flow

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Announcements

- Problem Set due Friday

- Lab 2 due Sunday

- Office Hours Friday 13:30 – 14:30

Today: Program control flow

- High level languages have many ways to control the order of execution in a program: if, if-else, for loops, while loops

- Today we will look at how these higher order concepts are built out of MIPS control flow instructions

Control Flow

- Recall the basic instruction cycle
  - IR = Memory[PC]
  - PC = PC + 4

- Both branch and jump instructions change the value of the program counter

Control Flow - Instructions

- Conditional
  - beq, bne: compare two registers and branch depending on the comparison
  - Change the value of the program counter if a condition is true

- Unconditional
  - j, jal, jr: jump to a location
  - Always change the value of the program counter

Control Flow - Labels

- In assembly, we use labels to help us guide control flow. Labels can be the target of branch or jump instructions.

- Example:

```
j Label

…

Label:   add $t1, $t0, $t2
```

- Assemblers are responsible for translating labels into addresses.

C Code

```
if (X == 0)
   X = Y + Z;
```

Assuming X, Y, and Z are integers in registers $t0, $t1, and $t2, respectively, which are the equivalent assembly instructions?

A
```
        beq $t0,$zero, Label
Label: add $t0, $t1, $t2
```

D – None of these is correct.

B
```
        beq $t0,$zero, Label
        add $t0, $t1, $t2
Label:
```

C
```
        bne $t0,$zero, Label
        add $t0, $t1, $t2
Label:
```

If (x < y): Set Less Than

- Set result to 1 if a condition is true
  - Otherwise, set to 0
- `slt rd, rs, rt`
  - if (rs < rt) rd = 1; else rd = 0;
- `slti rt, rs, constant`
  - if (rs < constant) rt = 1; else rt = 0;
- Use in combination with beq, bne

```
slt $t0, $s1, $s2  # if ($s1 < $s2)
bne $t0, $zero, L  #    branch to L
```

Branch Instruction Design

- Why not `blt`, `bge`, etc?
- Hardware for <, ≥, … slower than =, ≠
  - Combining with branch involves more work per instruction
  - `beq` and `bne` are the common case

High level code often has code like this:

```
if (i < j) {
    i = i + 1;
}
```

Assume $t0 has *i* and $t1 has *j*. Which of the following is the correct translation of the above code to MIPS assembly (recall $zero is always 0):

```
        slt $t2, $t0, $t1
        bne $t2, $zero, x
        addi $t0, $t0, 1
x:      next instruction
```
A

```
        slt $t2, $t0, $t1
        bne $t2, $zero, x
x:      addi $t0, $t0, 1
        next instruction
```
B

```
        slt $t2, $t0, $t1
        beq $t2, $zero, x
        addi $t0, $t0, 1
x:      next instruction
```
C

D | None of the above |

slt rd, rs, rt
    if (rs < rt) rd = 1; else rd = 0;

Signed vs. Unsigned

- Signed comparison: `slt`, `slti`

- Unsigned comparison: `sltu`, `sltui`

slt vs sltu

$s0 = 1111 1111 1111 1111 1111 1111 1111 1111

$s1 = 0000 0000 0000 0000 0000 0000 0000 0001

	slt $t0, $s0, $s1	sltu $t0, $s0, $s1
A	$t0 = 1	$t0 = 1
B	$t0 = 0	$t0 = 1
C	$t0 = 0	$t0 = 0
D	$t0 = 1	$t0 = 0

```
slt rd, rs, rt
```
if (rs < rt) rd = 1; else rd = 0;

Jump! Jump!

- `j label`
  - Go directly to the label (i.e., PC = label)

- `jr register`
  - Go directly to the label specified in the register

C Code

```
if (X == 0)
    X = Y + Z;
else
    X = Z + Z;
```

Assuming X, Y, and Z are integers in registers $t0, $t1, and $t2, respectively, which are the equivalent assembly instructions?

A

```
     bne    $t0, $zero, x
     add    $t0, $t1, $t2
x:   add    $t0, $t2, $t2
```

B

```
     bne $t0, $zero, x
        add $t0, $t1, $t2
        j endif
x:   add $t0, $t2, $t2
endif:
```

C

```
        bne $t0, $zero, x
        j endif
        add $t0, $t1, $t2
x:    add $t0, $t2, $t2
endif:
```

D – None of the above

C Code

```
for (i = 0; i < 10; i++){
    sum = sum + A[i];
}
```

Assume the base address of A is in $t0 and sum is in $s0. Elements of A are words. What is the equivalent assembly?

A
```
        li      $t2, 10
        move    $t1,  $zero
for:    beq     $t1, $t2, end
        lw      $t3, $t1($t0)
        add     $s0, $s0, $t3
        addi    $t1, $t1, 1
        j       for
end:
```

B
```
        li      $t2, 10
        move    $t1, $zero
for:    beq     $t1, $t2, end
        lw      $t3, 0($t0)
        add     $s0, $s0, $t3
        addi    $t0, $t0, 4
        addi    $t1, $t1, 1
        j       for
end:
```

C – More than one of these

D – None of these

How to access an array in a for loop

- Can't programmatically change the offset

- Need to change the *base address* instead

- Add 4 to the base address every time you want to move up an element of the array

```c
for (i=0; i < 10; i++){
  A[i] = 0;
}
```

*Assume base address of A is in $s3

```
        move  $s0, $zero
        li    $s1, 40
Loop:   beq   $s0, $s1, End
        add   $s4, $s3, $s0
        sw    $zero, 0($s4)
        addi  $s0, $s0, 4
        j     Loop
End:
```

Jump and Link

`jal Label`

– Address of following instruction put in $ra

– Jumps to target address

What is the most common use of a jal instruction and why?

	Most common use	Best answer
A	Procedure call	Jal stores the next instruction in your current function so the called function knows where to return to.
B	Procedure call	Jal enables a long jump and most procedures are a fairly long distance away
C	If/else	Jal lets you go to the if while storing pc+4 (else)
D	If/else	Jal enables a long branch and most if statements are a fairly long distance away
E	None of the above	

Reading

- Next lecture: Procedures
  - Section 2.9

- Problem set: Due Friday

- Lab 2: Due Sunday