CSCI 210: Computer Organization
Lecture 11: Control Flow

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Announcements

- Problem Set due Friday
- Lab 2 due Sunday
- Office Hours Tuesday 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
```

B

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

C

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

D – None of these is correct.

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

A

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

B

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

C

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

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 address 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?

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

A

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

B

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

C

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

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

*Assume base address of A is in $s3

```
      move  $t0, $zero
      li    $t1, 40
loop: beq   $t0, $t1, end
      add   $t4, $s3, $t0
      sw    $zero, 0($t4)
      addi  $t0, $t0, 4
      j     loop
end:
```

Jump and Link

`jal Label`

- Address of following instruction put in $ra
- Jumps to target address given by label

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