Flow of Control -- Conditional branch instructions

- You can compare directly
  - Equality or inequality of two registers
  - One register with 0 (>, <, ≥, ≤)
- and branch to a target specified as
  - a signed displacement expressed in *number of instructions* (not number of bytes) from the instruction *following* the branch
  - in assembly language, it is **highly** recommended to use labels and branch to labeled target addresses because:
    - the computation above is too complicated
    - some pseudo-instructions are translated into two real instructions

Examples of branch instructions

```
Beq     rs,rt,target    #go to target if rs = rt
Beqz    rs, target      #go to target if rs = 0
Bne     rs,rt,target    #go to target if rs != rt
Bltz    rs, target      #go to target if rs < 0
```

etc.

but note that you cannot compare directly 2 registers for <, > …

Any idea why?

Comparisons between two registers

- Use an instruction to set a third register

```
slt     rd,rs,rt     #rd = 1 if rs < rt else rd = 0
sltu    rd,rs,rt     #same but rs and rt are considered unsigned
```

- Example: Branch to Lab1 if $5 < $6

```
slt     $10,$5,$6    #$10 = 1 if $5 < $6 otherwise $10 = 0
bnez    $10,Lab1     # branch if $10 =1, i.e., $5<$6
```

- There exist pseudo instructions to help you!

```
blt     $5,$6,Lab1   # pseudo instruction translated into
                     # slt   $1,$5,$6
                     # bne  $1,$0,Lab1
```

Note the use of register 1 by the assembler and the fact that computing the address of Lab1 requires knowledge of how pseudo-instructions are expanded

Unconditional transfer of control

- Can use "beqz $0, target"
  - Very useful but limited range (± 32K instructions)
- Use of Jump instructions

```
j       target    #special format for target byte address (26 bits)
jr      $rs       #jump to address stored in rs (good for switch
                  #statements and transfer tables)
```

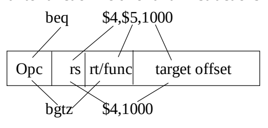
- Call/return functions and procedures

```
jal     target    #jump to target address; save PC of
                  #following instruction in $31 (aka $ra)
jr      $31       # jump to address stored in $31 (or $ra)
```

Also possible to use   jalr   rs,rd   # jump to address stored in rs; rd = PC of # following instruction in rd with default rd = $31

Branch addressing format

- Need Opcode, one or two registers, and an offset
  - No base register since offset added to PC
- When using one register (i.e., compare to 0), can use the second register field to expand the opcode
  - similar to function field for arith instructions



How to address operands

- The ISA specifies *addressing modes*
- MIPS, as a RISC machine has very few addressing modes
  - *register* mode. Operand is in a register
  - *base* or *displacement* or *indexed* mode
    - Operand is at address "register + 16-bit signed offset"
  - *immediate* mode. Operand is a constant encoded in the instruction
  - *PC-relative* mode. As *base* but the register is the PC

Some interesting instructions. Multiply

- Multiplying 2 32-bit numbers yields a 64-bit result
  - Use of HI and LO registers

```
Mult      rs,rt          #HI/LO = rs*rt
Multu     rs,rt
Then need to move the HI or LO or both to regular registers
mflo      rd             #rd = LO
mfhi      rd             #rd = HI
Once more the assembler can come to the rescue with a pseudo inst
mul       rd,rs,rt       #generates mult and mflo
                         #and mfhi if necessary
```

Some interesting instructions. Divide

- Similarly, divide needs two registers
  - LO gets the quotient
  - HI gets the remainder
- If an operand is negative, the remainder is not specified by the MIPS ISA.

Logic instructions

- Used to manipulate bits within words, set-up masks etc.
- A sample of instructions

```
and       rd,rs,rt       #rd=AND(rs,rt)
andi      rd,rs,immed
or        rd,rs,rt
xor       rd,rs,rt
```

- Immediate constant limited to 16 bits (zero-extended). If longer mask needed, use Lui.
- There is a pseudo-instruction NOT

```
not       rt,rs          #does 1's complement (bit by bit
                          #complement of rs in rt)
```

Example of use of logic instructions

- Create a *mask* of all 1's for the low-order byte of $6. Don't care about the other bits.

```
ori       $6,$6,0x00ff      #$6[7:0] set to 1's
```

- Clear high-order byte of register 7 but leave the 3 other bytes unchanged

```
lui       $5,0x00ff         #$5 = 0x00ff0000
ori       $5,$5,0xffff      #$5 = 0x00ffffff
and       $7,$7,$5          #$7 =0x00…… (…whatever was
                            #there before)
```

Shift instructions

- Logical shifts -- Zeroes are inserted

```
sll       rd,rt,shm      #left shift of shm bits; inserting 0's on
                         #the right
srl       rd,rt,shm      #right shift of shm bits; inserting 0's
                         #on the left
```

- Arithmetic shifts (useful only on the right)
  - sra rd,rt,shm # Sign bit is inserted on the left
- Example let $5 = 0xff00 0000

```
    sll    $6,$5,3       #$6 = 0xf800 0000
    srl    $6,$5,3       #$6 = 0x1fe0 0000
    sra    $6,$5,3       #$6 = 0xffe0 0000
```

Example -- High-level language

```
int a[100];
int i;

for (i=0; i<100; i++){
        a[i] = 5;
}
```

Assembly language version

Assume: start address of array a in r15.
We use r8 to store the value of i and r9 for the value 5

```
        add     $8,$0,$0        #initialize i
        li      $9,5            #r9 has the constant 5
Loop:   mul     $10,$8,4        #r10 has i in bytes
                                #could use a shift left by 2
        addu    $14,$10,$15     #address of a[i]
        sw      $9,0($14)       #store 5 in a[i]
        addiu   $8,$8,1         #increment i
        blt     $8,100,Loop     #branch if loop not finished
                                #taking lots of liberty here!
```

Machine language version (generated by SPIM)

```
[0x00400020]   0x00004020  add $8, $0, $0       ; 1: add    $8,$0,$0
[0x00400024]   0x34090005  ori $9, $0, 5        ; 2: li     $9,5
[0x00400028]   0x34010004  ori $1, $0, 4        ; 3: mul    $10,$8,4
[0x0040002c]   0x01010018  mult $8, $1
[0x00400030]   0x00005012  mflo $10
[0x00400034]   0x014f7021  addu $14, $10, $15   ; 4: addu   $14,$10,$15
[0x00400038]   0xadc90000  sw $9, 0($14)        ; 5: sw     $9,0($14)
[0x0040003c]   0x25080001  addiu $8, $8, 1      ; 6: addiu  $8,$8,1
[0x00400040]   0x29010064  slti $1, $8, 100     ; 7: blt    $8,100,Loop
[0x00400044]   0x1420fff9  bne $1, $0, -28 [Loop-0x00400044]
```