Testing and Branching

CSE 410, Spring 2009

Computer Systems

http://www.cs.washington.edu/410

Reading and References

- *Computer Organization and Design*
  - » Section 2.6, Logical Operations
  - » Section 2.7, Instructions for Making Decisions
  - » Section B.9, SPIM
  - » Section B.10 through page B-50, MIPS R2000 Assembly Language

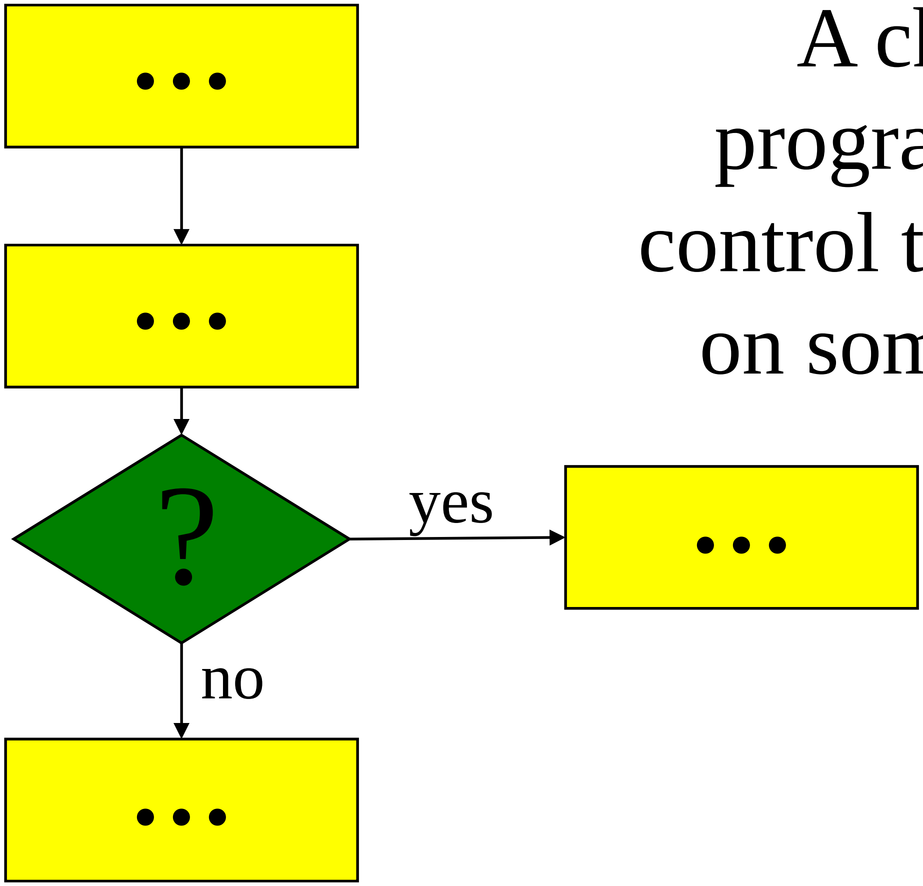
Control Flow

- All interesting programs have:
  - » Loops (while, for, do-while)
    - With an occasional break or continue
  - » Conditionals (if, switch)
- Machines have:
  - » goto
  - » conditional goto
- Have to synthesize what we want from that

goto considered harmful

- "Oh what a tangled web we weave, When first we practice to deceive!"
  - » Sir Walter Scott
- Branching in assembly language can turn your program into a rat's nest that cannot be debugged
- Keep control flow simple and logical
- Use comments describing the overall logic
  - » (if, while, for, … pseudo-code is often great!)

Conditional Branch



A change in the program’s flow of control that depends on some condition

Branch instructions

- Branch instructions are I-format instructions
  - » op code field
  - » two register fields
  - » 16-bit offset field
- Simplest branches check for equality
  - » **`beq $t0, $t1, address`**
  - » **`bne $t0, $t1, address`**
- Meaning: if condition is true, set **`PC = address`**
  - » i.e., fetch next instruction from **`address`**

if (i==j) then a=b;

- Assume all values are in registers
- Note that the test is inverted compared to **`if`**!

```
# $t0=i, $t1=j, $s0=a, $s1=b

     bne  $t0, $t1, skip
     move $s0, $s1
skip:
```

while (s[i]==k) i = i+j;

```
# $s0=addr(s), $v1=i, $a0=k, $a1=j

loop:
    sll     $v0,$v1,2     # v0 = 4*i
    addu    $v0,$s0,$v0   # v0 = addr(s[i])
    lw      $v0,0($v0)    # v0 = s[i]
    addu    $v1,$v1,$a1   # i = i+j
    beq     $v0,$a0,loop # loop if equal
    subu    $v1,$v1,$a1   # i = i-j
```

for (i=0; i<10; i++) s[i] = i;

```
# $s0=addr(s), $t1=i
  move    $t1,$zero      # i = 0
loop:
  sll     $t0,$t1,2      # t0 = i*4
  addu    $t0,$s0,$t0    # t0 = addr(s[i])
  sw      $t1,0($t0)     # s[i] = i
  addu    $t1,$t1,1      # i++
  slt     $t0,$t1,10     # if (i<10) $t0=1
  bnez    $t0,loop       # loop if (i<10)
```

How do we encode the destination?

- Calculating the destination address
  - » 4*(the 16-bit offset value) is added to the Program Counter (PC)
  - » This is calculated with the *incremented* value of the PC *after* the branch instruction is fetched
- The offset is a word offset in this case
- The base register is always the PC, so we don't need to specify it in the instruction
- Covers a range of 2^{16} words (64 KW)

Comparison instructions

- For comparisons other than equality
  - » **`slt`** : set less than
  - » **`sltu`** : set less than unsigned
  - » **`slti`** : set less than constant value
  - » **`sltiu`** : set less than unsigned constant

- set t0 to 1 if t1<t2, otherwise set to 0

```
slt $t0, $t1, $t2
```

Pseudo-instructions

- The assembler is your friend and will build instruction sequences for you
- Original code:

```
bge   $a0,$t1,end    # if a0>=t1 jump
```

  - Pseudo-instruction; no such instruction in the real processor hardware

- Actual instructions:

```
slt   $at,$a0,$t1    # if a0<t1 at=true
beq   $at,$0,end     # jump if at==false
```

Jump Instructions

- Jump instructions provide longer range than branch instructions
- 26-bit word offset in J-format instructions
  - » j : jump
  - » jal : jump and link (store return address)
- 32-bit address in register jumps
  - » jr : jump through register
  - » jalr : jump through register and link

J-format fields

op code	word offset
6 bits	*26 bits*

- The word offset value is multiplied by 4 to create a byte offset
  - » the result is 28 bits wide
- Then concatenated with top 4 bits of PC to make a 32 bit destination address
  - » i.e., can’t jump outside a 256MB segment (not a problem in most real code)

Important Jumps

- Jump and link (**`jal`**)
  - » call procedure and store return address in $ra
- Jump through register (**`jr`**)
  - » return to caller using the address in $ra
- We will talk about procedure calls in excruciating detail shortly