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CS61C : Machine Structures

Lecture #7 – MIPS Decisions

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Review

- **In MIPS Assembly Language:**
  - Registers replace C variables
  - One Instruction (simple operation) per line
  - Simpler is better, smaller is faster
- **Memory is byte-addressable, but `lw` and `sw` access one word at a time.**
- **A pointer (used by `lw` and `sw`) is just a memory address, so we can add to it or subtract from it (using offset).**
- **New Instructions:**

  `add, addi, sub, lw, sw`
- **New Registers:**

  C Variables: `$s0` - `$s7`

  Temporary Variables: `$t0` - `$t9`

  Zero: `$zero`

So Far...

- All instructions so far only manipulate data…we've built a calculator.
- In order to build a computer, we need ability to make decisions…
- C (and MIPS) provide labels to support "goto" jumps to places in code.
  - C: Horrible style; MIPS: Necessary!
- Heads up: pull out some papers and pens, you'll do an in-class exercise!

C Decisions: `if` Statements

- 2 kinds of `if` statements in C
  - `if (`*condition*`)` *clause*
  - `if (`*condition*`)` *clause1* `else` *clause2*
- Rearrange 2nd `if` into following:

```
if   (condition) goto L1;
      clause2;
      goto L2;
L1:   clause1;

L2:
```

- Not as elegant as `if-else`, but same meaning

MIPS Decision Instructions

- **Decision instruction in MIPS:**
  - `beq    register1, register2, L1`
  - `beq` is "Branch if (registers are) equal"
    Same meaning as (using C):
    `if  (register1==register2) goto L1`
- **Complementary MIPS decision instruction**
  - `bne    register1, register2, L1`
  - `bne` is "Branch if (registers are) not equal"
    Same meaning as (using C):
    `if  (register1!=register2) goto L1`
- **Called conditional branches**

MIPS Goto Instruction

- In addition to conditional branches, MIPS has an unconditional branch:

```
j    label
```

- Called a Jump Instruction: jump (or branch) directly to the given label without needing to satisfy any condition
- Same meaning as (using C):
```
goto label
```
- Technically, it's the same as:

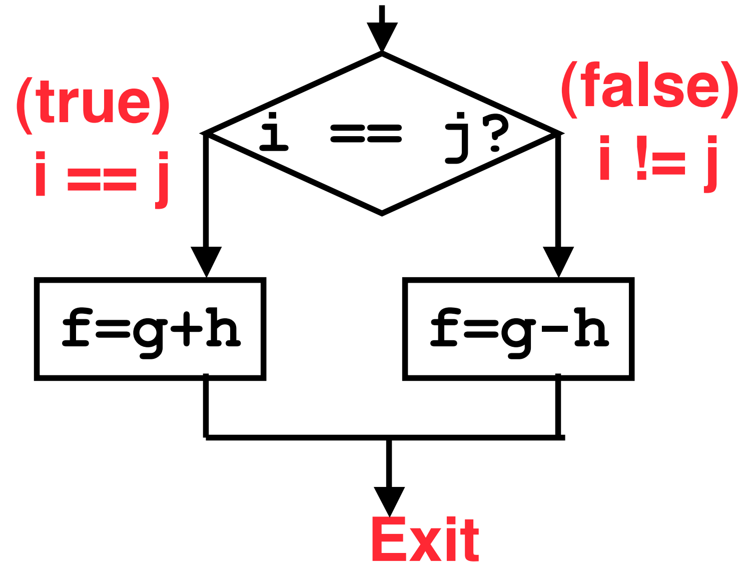
```
beq     $0,$0,label
```

since it always satisfies the condition.

Compiling C `if` into MIPS (1/2)

- Compile by hand

```
if (i == j) f=g+h;
else f=g-h;
```



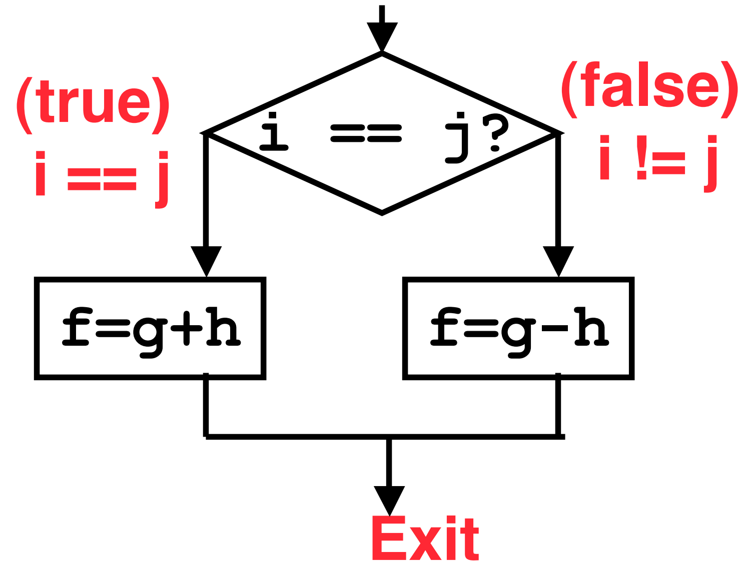
- Use this mapping:

```
f: $s0
g: $s1
h: $s2
i: $s3
j: $s4
```

Compiling C `if` into MIPS (2/2)

- Compile by hand

```
if (i == j) f=g+h;
else f=g-h;
```



- Final compiled MIPS code:

```
        beq $s3,$s4,True   # branch i==j
        sub $s0,$s1,$s2    # f=g-h(false)
        j   Fin            # goto Fin
True:   add $s0,$s1,$s2    # f=g+h (true)
Fin:
```

Note: Compiler automatically creates labels to handle decisions (branches). Generally not found in HLL code.

Overflow in Arithmetic (1/2)

- Reminder: Overflow occurs when there is a mistake in arithmetic due to the limited precision in computers.
- Example (4-bit unsigned numbers):

+15	1111
+3	0011
+18	10010

  - But we don't have room for 5-bit solution, so the solution would be 0010, which is +2, and wrong.

Overflow in Arithmetic (2/2)

- **Some languages detect overflow (Ada), some don't (C)**
- **MIPS solution has 2 kinds of arithmetic instructions to recognize 2 choices:**
    - **add (`add`), add immediate (`addi`) and subtract (`sub`) cause overflow to be detected**
    - **add unsigned (`addu`), add immediate unsigned (`addiu`) and subtract unsigned (`subu`) do not cause overflow detection**
- **Compiler selects appropriate arithmetic**
    - **MIPS C compilers produce `addu, addiu, subu`**

Two Logic Instructions

- 2 lectures ago we saw `add`, `addi`, `sub`
- Here are 2 more new instructions
- Shift Left: `sll $s1,$s2,2 #s1=s2<<2`
  - Store in `$s1` the value from `$s2` shifted 2 bits to the left, inserting 0's on right; << in C
  - Before: 0000 0002$_{hex}$
    0000 0000 0000 0000 0000 0000 0000 0010$_{two}$
  - After: 0000 000<u>8</u>$_{hex}$
    0000 0000 0000 0000 0000 0000 0000 10<u>00</u>$_{two}$
  - What arithmetic effect does shift left have?
- Shift Right: `srl` is opposite shift; >>

Loops in C/Assembly (1/3)

- Simple loop in C; `A[]` is an array of `int`s

```
do {
        g = g + A[i];
        i = i + j;
  } while (i != h);
```

- Rewrite this as:

```
Loop: g = g + A[i];
      i = i + j;
      if (i != h) goto Loop;
```

- Use this mapping:

```
  g,   h,   i,   j,  base of A
$s1, $s2, $s3, $s4, $s5
```

Loops in C/Assembly (2/3)

- **Final compiled MIPS code:**

```
Loop: sll  $t1,$s3,2    #$t1= 4*i
      add  $t1,$t1,$s5  #$t1=addr A
      lw   $t1,0($t1)   #$t1=A[i]
      add  $s1,$s1,$t1  #g=g+A[i]
      add  $s3,$s3,$s4  #i=i+j
      bne  $s3,$s2,Loop# goto Loop
                        # if i!=h
```

- **Original code:**

```
Loop: g = g + A[i];
      i = i + j;
      if (i != h) goto Loop;
```

Loops in C/Assembly (3/3)

- There are three types of loops in C:
  - `while`
  - `do… while`
  - `for`
- Each can be rewritten as either of the other two, so the method used in the previous example can be applied to `while` and `for` loops as well.
- Key Concept: Though there are multiple ways of writing a loop in MIPS, the key to decision making is conditional branch

Peer Instruction

We want to translate `*x = *y` into MIPS

(`x`, `y` ptrs stored in: `$s0 $s1`)

```
A: add $s0,    $s1, zero
B: add $s1,    $s0, zero
C: lw  $s0, 0($s1)
D: lw  $s1, 0($s0)
E: lw  $t0, 0($s1)
F: sw  $t0, 0($s0)
G: lw  $s0, 0($t0)
H: sw  $s1, 0($t0)
```

```
1: A
2: B
3: C
4: D
5: E→F
6: E→G
7: F→E
8: F→H
9: H→G
0: G→H
```

Administrivia

- Assignments
  - HW2 due tonight @ 11:59pm
  - HW3 due 7/8 @ 11:59pm
  - Proj1 due 7/12 @ 11:59pm (going up today)
- Third Section
  - Is going to happen, CS dept has approved funding, room, TA, etc.…
  - But Summer Sessions office in Wheeler slow to move
- Don't unplug stuff in lab!

Inequalities in MIPS (1/3)

- Until now, we've only tested equalities (`==` and `!=` in C). General programs need to test < and > as well.
- Create a MIPS Inequality Instruction:
  - "Set on Less Than"
  - Syntax: `slt reg1,reg2,reg3`
  - Meaning: `reg1 = (reg2 < reg3);`

```
if (reg2 < reg3)
     reg1 = 1;
else reg1 = 0;
```

Same thing…

  - In computereeze, "set" means "set to 1", "reset" means "set to 0".

Inequalities in MIPS (2/3)

- **How do we use this? Compile by hand:**

```
if (g < h) goto Less; #g:$s0,h:$s1
```

- **Answer: compiled MIPS code…**

```
slt $t0,$s0,$s1 # $t0 = 1 if g<h
bne $t0,$0,Less # goto Less
                # if $t0!=0
                # (if (g<h)) Less:
```

- **Branch if `$t0 != 0` ➔ (`g < h`)**
- **Register `$0` always contains the value `0`, so `bne` and `beq` often use it for comparison after an `slt` instruction.**
- **A `slt` ➔ `bne` pair means `if(… < …)goto…`**

Inequalities in MIPS (3/3)

- Now, we can implement <, but how do we implement >, ≤ and ≥ ?
- We could add 3 more instructions, but:
  - MIPS goal: Simpler is Better
- Can we implement ≤ in one or more instructions using just `slt` and the branches?
- What about >?
- What about ≥?

Immediates in Inequalities

- There is also an immediate version of `slt` to test against constants: `slti`
  - Helpful in `for` loops

C

```
if (g >= 1) goto Loop
```

MIPS

```
Loop: . . .

slti $t0,$s0,1      # $t0 = 1 if
                    # $s0<1 (g<1)
beq  $t0,$0,Loop    # goto Loop
                    # if $t0==0
                    # (if (g>=1))
```

An `slt` → `beq` pair means `if(… ≥ …)goto…`

What about unsigned numbers?

- Also unsigned inequality instructions:

  `sltu`, `sltiu`

…which sets result to 1 or 0 depending on unsigned comparisons

- What is value of `$t0`, `$t1`?

(`$s0 = FFFF FFFA`$_{hex}$, `$s1 = 0000 FFFA`$_{hex}$)

```
slt $t0, $s0, $s1
sltu $t1, $s0, $s1
```

MIPS Signed vs. Unsigned – diff meanings!

- MIPS Signed v. Unsigned is an "overloaded" term
  - Do/Don't sign extend (`lb`, `lbu`)
  - Don't overflow (`addu`, `addiu`, `subu`, `multu`, `divu`)
  - Do signed/unsigned compare (`slt`, `slti`/`sltu`, `sltiu`)

Example: The C Switch Statement (1/3)

- Choose among four alternatives depending on whether `k` has the value 0, 1, 2 or 3. Compile this C code:

```
switch (k) {
 case 0: f=i+j; break; /* k=0 */
 case 1: f=g+h; break; /* k=1 */
 case 2: f=g-h; break; /* k=2 */
 case 3: f=i-j; break; /* k=3 */
}
```

Example: The C Switch Statement (2/3)

- This is complicated, so simplify.
- Rewrite it as a chain of if-else statements, which we already know how to compile:

```
if(k==0) f=i+j;
  else if(k==1) f=g+h;
    else if(k==2) f=g-h;
      else if(k==3) f=i-j;
```

- Use this mapping:

```
f:$s0, g:$s1, h:$s2,
i:$s3, j:$s4, k:$s5
```

Example: The C Switch Statement (3/3)

- **Final compiled MIPS code:**

```
      bne $s5,$0,L1      # branch k!=0
      add  $s0,$s3,$s4 #k==0 so f=i+j
      j    Exit          # end of case so Exit
L1:   addi $t0,$s5,-1   # $t0=k-1
      bne  $t0,$0,L2    # branch k!=1
      add  $s0,$s1,$s2 #k==1 so f=g+h
      j    Exit          # end of case so Exit
L2:   addi $t0,$s5,-2   # $t0=k-2
      bne  $t0,$0,L3    # branch k!=2
      sub  $s0,$s1,$s2 #k==2 so f=g-h
      j    Exit          # end of case so Exit
L3:   addi $t0,$s5,-3   # $t0=k-3
      bne  $t0,$0,Exit # branch k!=3
      sub  $s0,$s3,$s4 #k==3 so f=i-j
Exit:
```

Peer Instruction

```
Loop:addi $s0,$s0,-1    # i = i - 1
     slti $t0,$s1,2     # $t0 = (j < 2)
     beq  $t0,$0 ,Loop  # goto Loop if $t0 == 0
     slt  $t0,$s1,$s0   # $t0 = (j < i)
     bne  $t0,$0 ,Loop  # goto Loop if $t0 != 0
```

($s0=i, $s1=j)

What C code properly fills in the blank in loop below?

```
do {i--;} while(__);
```

```
1: j < 2 && j < i
2: j ≥ 2 && j < i
3: j < 2 && j ≥ i
4: j ≥ 2 && j ≥ i
5: j > 2 && j < i
6: j < 2 || j < i
7: j ≥ 2 || j < i
8: j < 2 || j ≥ i
9: j ≥ 2 || j ≥ i
0: j > 2 || j < i
```

"And in Conclusion..."

- A Decision allows us to decide what to execute at run-time rather than compile-time.
- C Decisions are made using conditional statements within `if`, `while`, `do while`, `for`.
- MIPS Decision making instructions are the conditional branches: `beq` and `bne`.
- In order to help the conditional branches make decisions concerning inequalities, we introduce a single instruction: "Set on Less Than" called `slt`, `slti`, `sltu`, `sltiu`
- Unsigned add/sub don't cause overflow
- New MIPS Instructions:

```
beq, bne, j, sll, srl
slt, slti, sltu, sltiu
addu, addiu, subu
```