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CS61C : Machine Structures

Lecture 10 – Introduction to MIPS Decisions II

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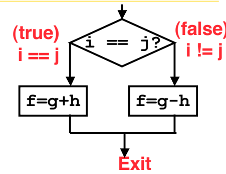
Compiling C `if` into MIPS (2/2)

- 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.

Review

- 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).
- 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`.
- New Instructions:

  `lw, sw, beq, bne, j`

From last time: Loading, Storing bytes 1/2

- In addition to word data transfers (`lw`, `sw`), MIPS has byte data transfers:
- load byte: `lb`
- store byte: `sb`
- same format as `lw`, `sw`

Loading, Storing bytes 2/2

- What do with other 24 bits in the 32 bit register?
  - `lb`: sign extends to fill upper 24 bits

`xxxx xxxx xxxx xxxx xxxx xxxx xzzz zzzz`

...is copied to "sign-extend"

byte loaded

This bit

- Normally don't want to sign extend chars
- MIPS instruction that doesn't sign extend when loading bytes:

  load byte unsigned: `lbu`

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
<u>+3</u>	<u>0011</u>
+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 is 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: $0000\ 0008_{hex}$
    $0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 1000_{two}$
  - 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

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`)

Administrivia

- Proj1 due in 9 days – start EARLY!
  - Out on Wed, due Friday [extended date]
  - The following hw (smaller) still due Wed
- We have a midterm & review date
  - Review: Sun 2005-03-06, Loc/Time TBA
  - Midterm: Mon 2005-03-07, Loc/Time TBA
  - DSP or Conflicts? Email `acarle@cs`
- Dan's OH cancelled tomorrow
  - Go to the BEARS conference!

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

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
```


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…"

- 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`
- One can store and load (signed and unsigned) bytes as well as words
- Unsigned add/sub don't cause overflow
- New MIPS Instructions:

```
sll, srl
slt, slti, sltu, sltiu
addu, addiu, subu
```