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CS61C : Machine Structures

Lecture 10 – Introduction to MIPS Decisions II

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There is one handout today at the front and back of the room!

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Face Login? ⇒ NecSoft offers windows users an alternative way to log in – show your face to your computer's webcam! Do photos work too? Bad hair day?

crave.cnet.com/8301-1_105-9684222-1.html

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`

E.g., `lb $s0, 3($s1)`

contents of memory location with address = sum of "3" + contents of register `s1` is copied to the low byte position of register `s0`.

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" ← This bit; byte loaded

- 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
+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 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

- 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

Administrivia

- Project 1 due Friday!
  - (ok, Sunday, but tell your brain it's Friday!)
- Any other administrivia?

Inequalities in MIPS (1/4)

- Until now, we've only tested equalities (== and != in C). General programs need to test < and > as well.
- Introduce 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…

"set" means "set to 1",
"reset" means "set to 0".

Inequalities in MIPS (2/4)

- 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:
```

- 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 (3/4)

- 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 ≥?

Inequalities in MIPS (4/4)

```
# a:$s0,b:$s1
slt $t0,$s0,$s1 # $t0 = 1 if a<b
beq $t0,$0,skip # skip if a >= b
    <stuff>     # do if a<b
skip:
```

Two independent variations possible:

Use `slt $t0,$s1,$s0` instead of

`slt $t0,$s0,$s1`

Use `bne` instead of `beq`

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 terms *Signed/Unsigned* are "overloaded":
  - 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(__);`

```
0: j < 2 && j < i
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
```


"And in conclusion…"

- To help the conditional branches make decisions concerning inequalities, we introduce: "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
```