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CS61C : Machine Structures

Lecture 11 – Introduction to MIPS Procedures I

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Hi to Naim watching the webcat from Denmark!

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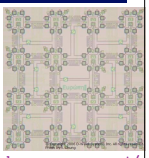
Quantum computing? ⇒ A "16-qubit superconducting adiabatic quantum computer" will be demoed at the Computer History Museum in Mountain View on 2007-02-13. Each qubit is connected to its 8 neighbors via a "tunable flux transformer". Most: wait and see…



dwave.wordpress.com/2007/01/19/quantum-computing-demo-announcement/

Review

- 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`

C functions

```
main() {
  int i,j,k,m;
  ...
  i = mult(j,k); ...
  m = mult(i,i); ...
}

/* really dumb mult function */

int mult (int mcand, int mlier){
  int product;

  product = 0;
  while (mlier > 0)  {
    product = product + mcand;
    mlier = mlier -1; }
  return product;
  }
```

What information must compiler/programmer keep track of?

What instructions can accomplish this?

Function Call Bookkeeping

- Registers play a major role in keeping track of information for function calls.
- Register conventions:
  - Return address `$ra`
  - Arguments `$a0, $a1, $a2, $a3`
  - Return value `$v0, $v1`
  - Local variables `$s0, $s1, … , $s7`
- The stack is also used; more later.

Instruction Support for Functions (1/6)

C

```
... sum(a,b);... /* a,b:$s0,$s1 */
}
int sum(int x, int y) {
   return x+y;
}
```

MIPS

```
address
1000
1004
1008
1012
1016

2000
2004
```

In MIPS, all instructions are 4 bytes, and stored in memory just like data. So here we show the addresses of where the programs are stored.

Instruction Support for Functions (2/6)

C

```
... sum(a,b);... /* a,b:$s0,$s1 */
}
int sum(int x, int y) {
   return x+y;
}
```

MIPS

```
address
1000 add  $a0,$s0,$zero   # x = a
1004 add  $a1,$s1,$zero   # y = b
1008 addi $ra,$zero,1016  #$ra=1016
1012 j    sum             #jump to sum
1016 ...

2000 sum: add $v0,$a0,$a1
2004 jr   $ra  # new instruction
```

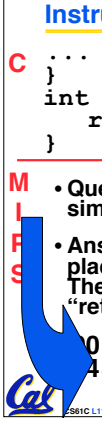
Instruction Support for Functions (3/6)

C
```
... sum(a,b);... /* a,b:$s0,$s1 */
}
int sum(int x, int y) {
   return x+y;
}
```

MIPS

- Question: Why use `jr` here? Why not simply use `j`?
- Answer: `sum` might be called by many places, so we can't return to a fixed place. The calling proc to `sum` must be able to say "return here" somehow.

```
0 sum: add $v0,$a0,$a1
4 jr   $ra  # new instruction
```



Instruction Support for Functions (4/6)

- Single instruction to jump and save return address: jump and link (`jal`)
- Before:

```
1008 addi $ra,$zero,1016 #$ra=1016
1012 j sum               #goto sum
```

- After:

```
1008 jal sum  # $ra=1012,goto sum
```

- Why have a `jal`? Make the common case fast: function calls are very common. (Also, you don't have to know where the code is loaded into memory with `jal`.)

Instruction Support for Functions (5/6)

- Syntax for `jal` (jump and link) is same as for `j` (jump):

```
jal label
```

- `jal` should really be called `laj` for "link and jump":
  - Step 1 (link): Save address of *next* instruction into `$ra` (Why next instruction? Why not current one?)
  - Step 2 (jump): Jump to the given label

Instruction Support for Functions (6/6)

- Syntax for `jr` (jump register):

```
jr register
```

- Instead of providing a label to jump to, the `jr` instruction provides a register which contains an address to jump to.
- Very useful for function calls:
  - `jal` stores return address in register (`$ra`)
  - `jr $ra` jumps back to that address

Administrivia

- Project 1 due tonight (um, start soon!)
  - TAs will be providing help in the lab!
    - Matt: Fri (today) 6pm on…
    - Michael: Su 3-6pm

Nested Procedures (1/2)

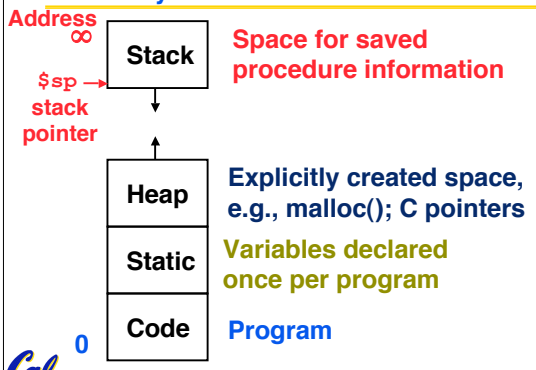
```
int sumSquare(int x, int y) {
    return mult(x,x)+ y;
}
```

- Something called `sumSquare`, now `sumSquare` is calling `mult`.
- So there's a value in `$ra` that `sumSquare` wants to jump back to, but this will be overwritten by the call to `mult`.
- Need to save `sumSquare` return address before call to `mult`.

Nested Procedures (2/2)

- In general, may need to save some other info in addition to `$ra`.
- When a C program is run, there are 3 important memory areas allocated:
  - Static: Variables declared once per program, cease to exist only after execution completes. E.g., C globals
  - Heap: Variables declared dynamically
  - Stack: Space to be used by procedure during execution; this is where we can save register values

C memory Allocation review



Using the Stack (1/2)

- So we have a register `$sp` which always points to the last used space in the stack.
- To use stack, we decrement this pointer by the amount of space we need and then fill it with info.
- So, how do we compile this?

```
int sumSquare(int x, int y) {
  return mult(x,x)+ y;
}
```

Using the Stack (2/2)

- Hand-compile `int sumSquare(int x, int y) { return mult(x,x)+ y; }`

```
sumSquare:
"push"  addi $sp,$sp,-8  # space on stack
        sw $ra, 4($sp)   # save ret addr
        sw $a1, 0($sp)   # save y

        add $a1,$a0,$zero # mult(x,x)
        jal mult          # call mult

        lw $a1, 0($sp)   # restore y
        add $v0,$v0,$a1  # mult()+y
        lw $ra, 4($sp)   # get ret addr
"pop"   addi $sp,$sp,8   # restore stack
        jr $ra
mult:   ...
```

Steps for Making a Procedure Call

1) Save necessary values onto stack.

2) Assign argument(s), if any.

3) `jal` call

4) Restore values from stack.

Rules for Procedures

- Called with a `jal` instruction, returns with a `jr $ra`
- Accepts up to 4 arguments in `$a0`, `$a1`, `$a2` and `$a3`
- Return value is always in `$v0` (and if necessary in `$v1`)
- Must follow register conventions

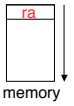
So what are they?

Basic Structure of a Function

Prologue

```
entry_label:
addi $sp,$sp, -framesize
sw $ra, framesize-4($sp)   # save $ra
save other regs if need be
```

Body ··· **(call other functions…)**



Epilogue

```
restore other regs if need be
lw $ra, framesize-4($sp)   # restore $ra
addi $sp,$sp, framesize
jr $ra
```


MIPS Registers

The constant 0	$0	$zero
Reserved for Assembler	$1	$at
Return Values	$2-$3	$v0-$v1
Arguments	$4-$7	$a0-$a3
Temporary	$8-$15	$t0-$t7
Saved	$16-$23	$s0-$s7
More Temporary	$24-$25	$t8-$t9
Used by Kernel	$26-27	$k0-$k1
Global Pointer	$28	$gp
Stack Pointer	$29	$sp
Frame Pointer	$30	$fp
Return Address	$31	$ra

(From COD 3rd Ed. green insert)
Use names for registers -- code is clearer!

Other Registers

- `$at`: may be used by the assembler at any time; unsafe to use
- `$k0-$k1`: may be used by the OS at any time; unsafe to use
- `$gp`, `$fp`: don't worry about them
- Note: Feel free to read up on `$gp` and `$fp` in Appendix A, but you can write perfectly good MIPS code without them.

Peer Instruction

```
int fact(int n){
 if(n == 0) return 1; else return(n*fact(n-1));}
```

When translating this to MIPS…

A. We COULD copy `$a0` to `$a1` (& then not store `$a0` or `$a1` on the stack) to store `n` across recursive calls.

B. We MUST save `$a0` on the stack since it gets changed.

C. We MUST save `$ra` on the stack since we need to know where to return to…

	ABC
0:	FFF
1:	FFT
2:	FTF
3:	FTT
4:	TFF
5:	TFT
6:	TTF
7:	TTT

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…"

- Functions called with `jal`, return with `jr $ra`.
- The stack is your friend: Use it to save anything you need. Just be sure to leave it the way you found it.
- Instructions we know so far
  - Arithmetic: `add, addi, sub, addu, addiu, subu`
  - Memory: `lw, sw`
  - Decision: `beq, bne, slt, slti, sltu, sltiu`
  - Unconditional Branches (Jumps): `j, jal, jr`
- Registers we know so far
  - All of them!