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**UCB CS61C : Machine Structures**

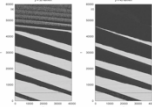
**Lecture 10 – Introduction to MIPS Procedures I**

Sr Lecturer SOE  
**Dan Garcia**

**2014-02-14**

**IN-CAR ALGORITHM COULD DISSOLVE TRAFFIC!**

"If cars broadcast their speeds to other vehicles" ... (and the speeds of cars were automatically controlled – you could still steer) ... "a simple in-car algorithm could help dissolve traffic jams as soon as they occur!". Key idea – be optimistic leaving the jam and defensive leading into it.



[www.technologyreview.com/blog/arxiv/27166/](http://www.technologyreview.com/blog/arxiv/27166/)



**Review**

- MIPS Machine Language Instruction: 32 bits representing a single instruction

R	opcode	rs	rt	rd	shamt	funct
I	opcode	rs	rt	immediate		
J	opcode	target address				

- Branches use PC-relative addressing, Jumps use absolute addressing.
- Disassembly is simple and starts by decoding opcode field. (more next lecture)



**C functions**

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

**What information must compiler/programmer keep track of?**

```
/* really dumb mult function */
int mult (int mcand, int mlrier){
  int product = 0;
  while (mlrier > 0) {
    product = product + mcand;
    mlrier = mlrier -1; }
  return product;
}
```

**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)**

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

address (shown in decimal)

**M  
I  
P  
S**

- 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)**

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

address (shown in decimal)

**M  
I  
P  
S**

- 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)

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

C

- Question: Why use `jr` here? Why not use `j`?

M

- 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.

I

P

S

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

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### 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 very common.
- Don't have to know where code is in memory with `jal`!

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### 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

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### 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

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### 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`.

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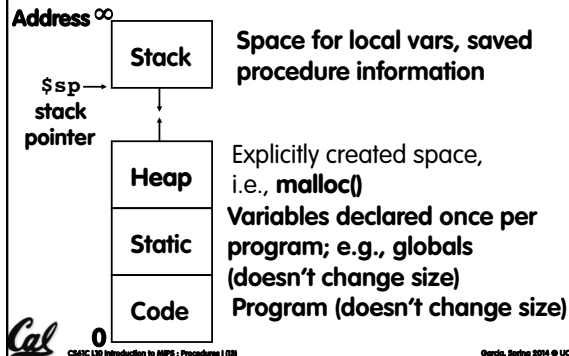
### Nested Procedures (2/2)

- 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 via `malloc`
  - Stack: Space to be used by procedure during execution; this is where we can save register values

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## C Memory Allocation



## 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;
}
```

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## Using the Stack (2/2)

```
Hand-compile int sumSquare(int x, int y) {
sumSquare:   return mult(x,x)+ y; }
    addi $sp,$sp,-8 # space on stack
    sw $ra, 4($sp) # save ret addr
    "push"     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
    "pop"     lw $ra, 4($sp) # get ret addr
    addi $sp,$sp,8 # restore stack
    jr $ra
```

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## Steps for Making a Procedure Call

- Save necessary values onto stack.
- Assign argument(s), if any.
- `jal call`
- Restore values from stack.

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## 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?

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## Basic Structure of a Function

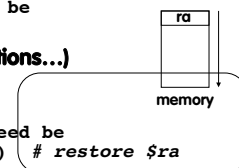
### Prologue

```
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
```



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## 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 green insert)  
Use names for registers -- code is clearer!

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## 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.

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## Peer Instruction

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

When translating this to MIPS...

- 1) We COULD copy \$a0 to \$a1 (& then not store \$a0 or \$a1 on the stack) to store n across recursive calls.
- 2) We MUST save \$a0 on the stack since it gets changed.
- 3) We MUST save \$ra on the stack since we need to know where to return to...

- 123  
a) FFF  
b) FFT  
c) FTF  
c) FTT  
d) TFF  
e) TTF  
e) TTT

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## "And in Conclusion..."

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

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