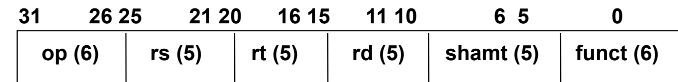
Lecture 09
Procedure Calls in MIPS

MIPS Instruction Types

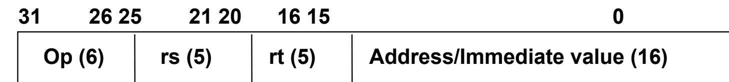
- **R-type: All operands are in registers**

  Assembly: add $9, $7, $8 # add rd, rs, rt: RF[rd] = RF[rs]+RF[rt]



- **I-Type: 1 operand = immediate value, others in registers**

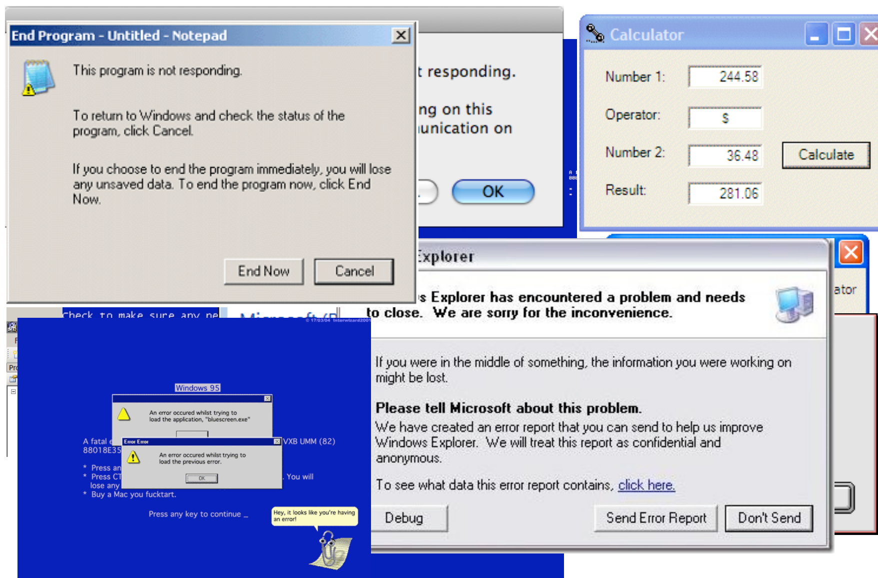
  Example: **lw** $s3, 32($t0) # **RF[19] = DM[RF[8]+32]**



- **J-type: only one operand: the target address**

  Example: j 3 # Goto addr. 3 x 4 (i.e. goto addr. 12)

Have you ever seen a message like this?



You didn't write this code...

- **Assembly language *procedure* was invoked**
- **Today:**
  - **How something like this happens**
    - **(Not the Microsoft OS, the procedure call!)**

Practical Procedures

For example:

```
int main(void) {
   int i;
   int j;

   j = power(i, 7);
}

int power(int i, int n) {
   int j, k;
   for (j=0; j<n; j++)
      k = i*i;
   return k;
}
```

Might look like this:

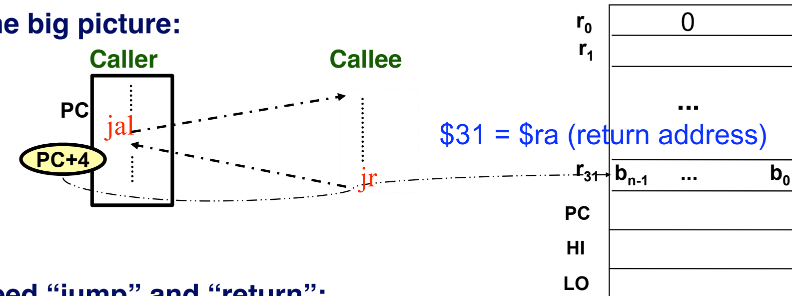
```
        i = $6                # i in an arg reg.

        addi $ 5, $0, 7       # arg reg. = 7
        j power
call:
        ....

power:  add $3, $0, $0
        subi $5, $5, 1
loop:   mult $6, $6, $6
        addi $3, $3, 1
        sub $11, $5, $3
        bneq $11, $0, loop
        add $2, $6, $0        # data in ret. reg.
        j call
```


MIPS Procedure Handling

- The big picture:



- Need "jump" and "return":
  - *jal ProcAddr* # issued in the caller
    - jumps to ProcAddr
    - save the return instruction address in $31
    - PC = JumpAddr, RF[31]=PC+4;
  - *jr $31* ($ra) # last instruction in the callee
    - jump back to the caller procedure
    - PC = RF[31]

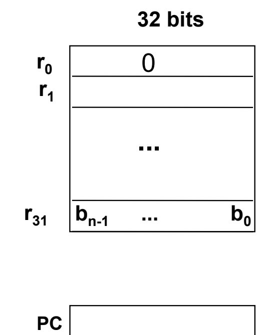
MIPS Registers

(and the "conventions" associated with them)

Name	R#	Usage	Preserved on Call
$zero	0	The constant value 0	n.a.
$at	1	Reserved for assembler	n.a.
$v0-$v1	2-3	Values for results & expr. eval.	no
$a0-$a3	4-7	Arguments	no
$t0-$t7	8-15	Temporaries	no
$s0-$s7	16-23	Saved	yes
$t8-$t9	24-25	More temporaries	no
$k0-$k1	26-27	Reserved for use by OS	n.a.
$gp	28	Global pointer	yes
$sp	29	Stack pointer	yes
$fp	30	Frame pointer	yes
$ra	31	Return address	yes

MIPS Procedure Handling (cont.)

- What about passing parameters and return values?
  - registers $4 - $7 ($a0-$a3) are used to pass first 4 parameters
  - returned values are in $2 and $3 ($v0-$v1)
- 32x32-bit GPRs (General purpose registers)
  - $0 = $zero
  - $2 - $3 = $v0 - $v1 (return values)
  - $4 - $7 = $a0 - $a3 (arguments)
  - $8 - $15 = $t0 - $t7 (temporaries)
  - $16 - $23 = $s0 - $s7 (saved)
  - $24 - $25 = $t8 - $t9 (more temporaries)
  - $31 = $ra (return address)



What if ... ?

- More complex procedure calls
  - What if your have more than 4 arguments?
  - What if your procedure requires more registers than available?
  - What about nested procedure calls?
  - What happens to $ra if proc1 calls proc 2 which calls proc3,…

More complex cases

- Register contents across procedure calls are designated as either caller or callee saved
- MIPS register conventions: (although could make caller/callee do all)
  - $t*, $v*, $a*: not preserved across call
    - caller saves them if required
  - $s*, $ra: preserved across call
    - callee saves them if required
  - See P&H FIGURE 2.18 (p.88) for a detailed register usage convention

Recall…

Name	R#	Usage	Preserved on Call
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$gp	28	Global pointer	yes
$sp	29	Stack pointer	yes
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$ra	31	Return address	yes

Procedure call essentials: Caller/Callee Mechanics

- Four places

Who does what when?

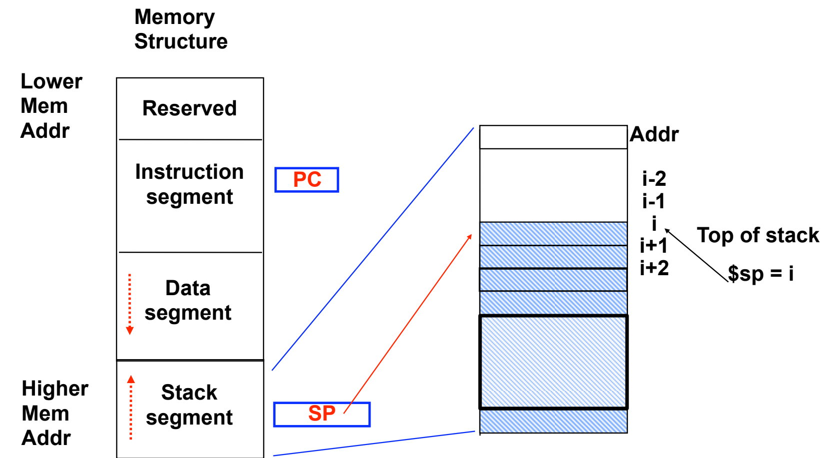
```
foo()
{

  1. caller at call time
  bar(42);

  4. caller after return

}
```

```
bar(int a)
{
  2. callee at entry
  int temp = 3;

  ...

  return(temp + a);
  3. callee at exit
}
```

Where is all this stuff saved to?

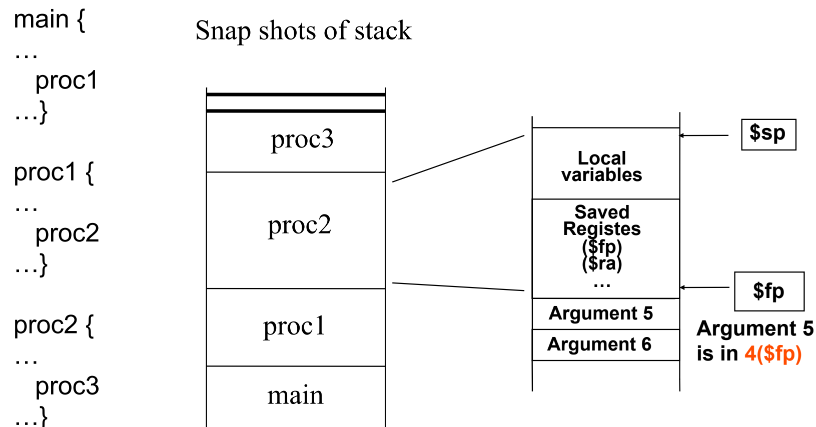
- Stack
  - A dedicated area of memory
  - First-In-Last-Out (FILO)
  - Used to
    - Hold values passed to a procedure as arguments
    - Save register contents when needed
    - Provide space for variables local to a procedure
- Stack operations
  - push: place data on stack (sw in MIPS)
  - pop: remove data from stack (lw in MIPS)
- Stack pointer
  - Stores the address of the top of the stack
  - $29 ($sp) in MIPS

Where is the stack located?



Call frames

- Each procedure is associated with a call frame
- Each frame has a frame pointer: $fp ($30)



Procedure call essentials: Good Strategy

- Caller at call time
  - put arguments in $a0..$a4
  - save any caller-save temporaries
  - jalr ..., $ra
- Callee at entry
  - allocate all stack space
  - save $ra + $s0..$s3 if necessary
- Callee at exit
  - restore $ra + $s0..$s3 if used
  - deallocate all stack space
  - put return value in $v0
- Caller after return
  - retrieve return value from $v0
  - restore any caller-save temporaries

do most work at callee entry/exit

most of the work

Procedure call essentials (4)

- Summary
  - Caller saves registers
    - (outside the agreed upon convention i.e. $ax) at point of call
  - Callee saves registers
    - (per convention i.e. $sx) at point of entry
  - Callee restores saved registers, and re-adjusts stack before return
  - Caller restores saved registers, and re-adjusts stack before resuming from the call

Examples:

- MIPS function call conventions
- Nested function calls
- Stack pointers and frame pointers
- Capstone example:
  - Recursive Factorial!

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