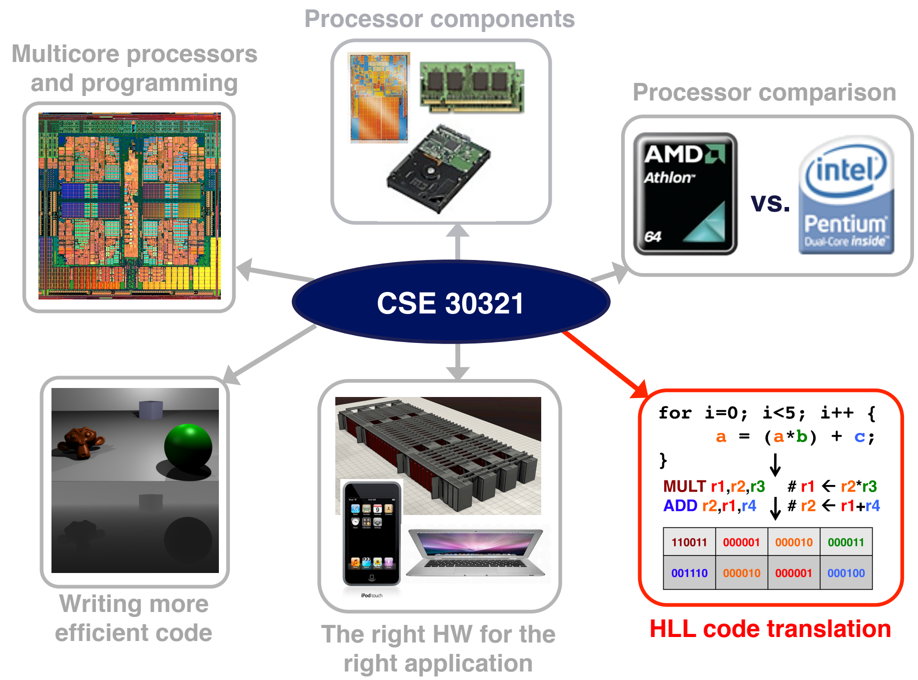
Lecture 07-09
MIPS Programs and Procedures

Suggested reading:
(HP Chapter 2.8)
(for extra examples, see Chapters 2.12 and 2.13)



Fundamental lesson(s)

- Over the next 3 lectures (using the MIPS ISA as context) I'll explain:
  - How functions are treated and processed in assembly
  - How system calls are enabled in assembly
  - How exceptions are handled in assembly

- I'll also explain why it's important that register conventions be followed

Why it's important…

- If you every write a compiler or OS some day, you will need to be aware of, and code for all of the issues to be discussed over the next 3 lectures

- If you understand what architectural overhead may be associated with (compiled) procedure calls, you should be able to write much more efficient HLL code

Practical Procedures

Have already seen that you don't necessarily make N copies of for loop body

Thus:

```
for (i=0; i<N; i++) {
      a = b + c;
      d = a + e;
      f = d + i;
}
```

Might look like this:

```
# N = $2, i = $3

      subi $2, $2, 1       # N = N -1
loop: add $4, $5, $6       # a = b + c
      add $7, $4, $8       # d = a + e
      add $9, $7, $10      # f  = d + i
      addi $3, $3, 1       # i = i + 1
      sub $11, $2, $3      # $11 = $3 - $2
      bneq $11, $0, loop   # if $11 != 0, loop
```

You wouldn't make multiple copies of a machine instruction function either…

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:

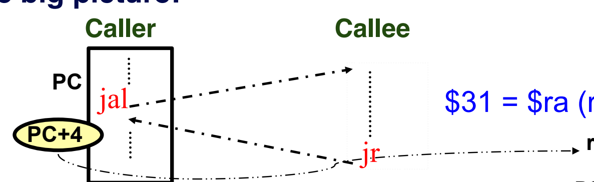
```
        i = $6              # i in an arg reg.

        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
```

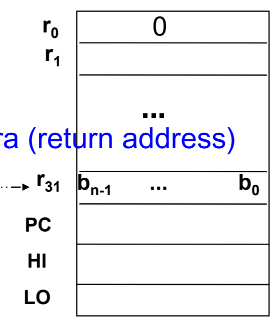
Advantage: Much greater code density.
(especially valuable for library routines, etc.)

Procedure calls are so common that there's significant architectural support.

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]**

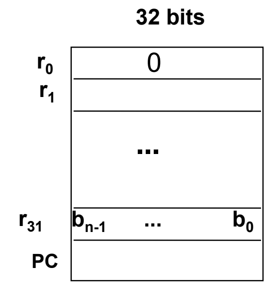
MIPS Registers

(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

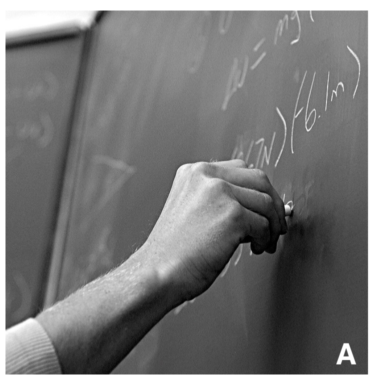
MIPS Procedure Handling (cont.)

- 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)



Take away: HW support for SW tasks.

Swap Procedure Example



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

Recall…

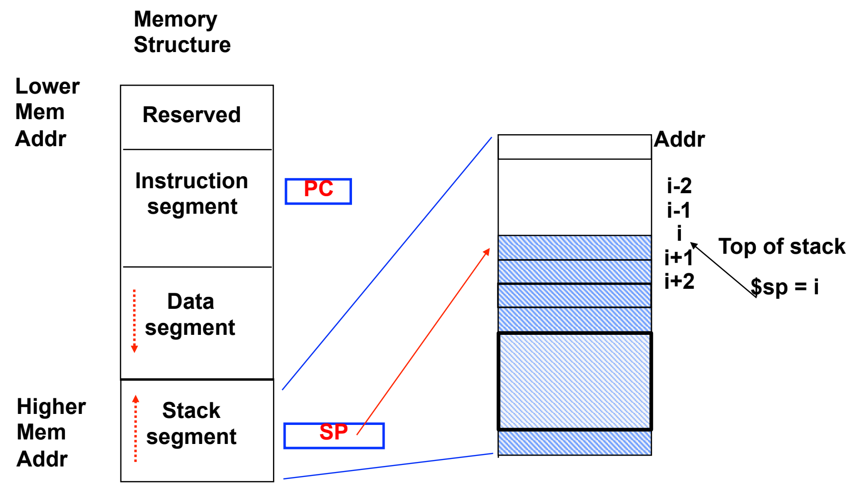
(MIPS registers and associated "conventions)

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

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

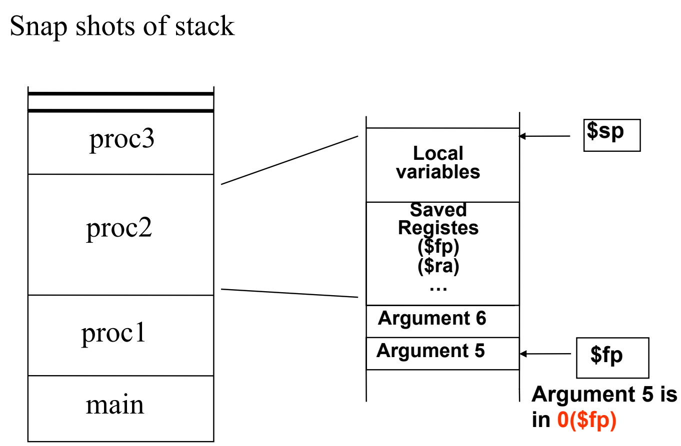
Where is the stack located?



Call frames

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

```
main {
…
  proc1
…}

proc1 {
…
  proc2
…}

proc2 {
…
  proc3
…}
```



Because $sp can change dynamically, often easier/intuitive to reference extra arguments via stable $fp – although can use $sp with a little extra math

Procedure call essentials: Good Strategy

- Caller at call time
  - put arguments in $a0..$a4
  - save any caller-save temporaries
  - jal ..., $ra
- Callee at entry
  - allocate all stack space
  - save $ra, $fp + $s0..$s7 if necessary
- Callee at exit
  - restore $ra, $fp + $s0..$s7 if used
  - deallocate all stack space
  - put return value in $v0
- Caller after return
  - retrieve return value from $v0
  - restore any caller-save temporaries

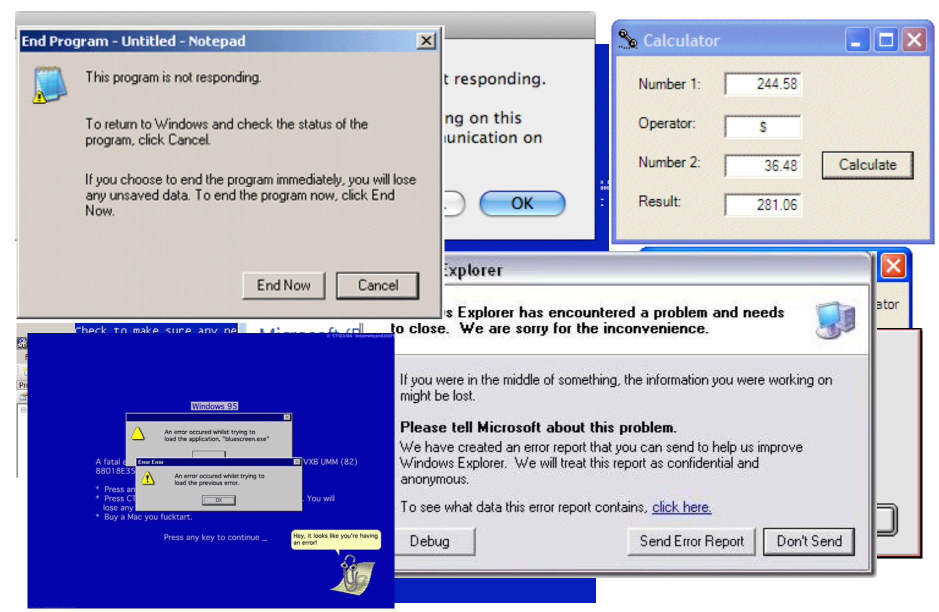
do most work at callee entry/exit

most of the work

Procedure call essentials

- 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

Why so strict?



Examples:

- Previous Exam Questions
- MIPS leaf procedure
- 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));
}
```