Procedures

Let's try to make the code reusable...

C code

```
int NumSpaces (char *s)
{
   int count = 0;
   while (*s) {
      if (*s++ == ' ') count++;
   }
   /* count contains the number of spaces */
   return count;
}
```

Procedures

Questions:

How does one...

- pass parameters?
- pass back the return value?
- start executing the function?
- return from the function?
- use registers?

First Attempt

pass parameters?	use register $4
pass back the return value?	use register $2
start executing the function?	use j
return from the function?	use j
use registers?	use any

Assembly

callee

```
NumSpaces:  addu $17,$0,$4
            ...
    $done:  addu $2,$0,$16
            j Return
```

caller

```
            ...
            j NumSpaces
   Return:  ...
            ...
```

Second Attempt

Might want to call function from multiple places...

start executing the function?	use `jal`
return from the function?	use `jr`

Assembly

callee

```
NumSpaces:  addu $17,$0,$4
            ...
    $done:  addu $2,$0,$16
            jr $31
```

caller

```
...
jal NumSpaces
...
...
```

What About Recursion?

C code

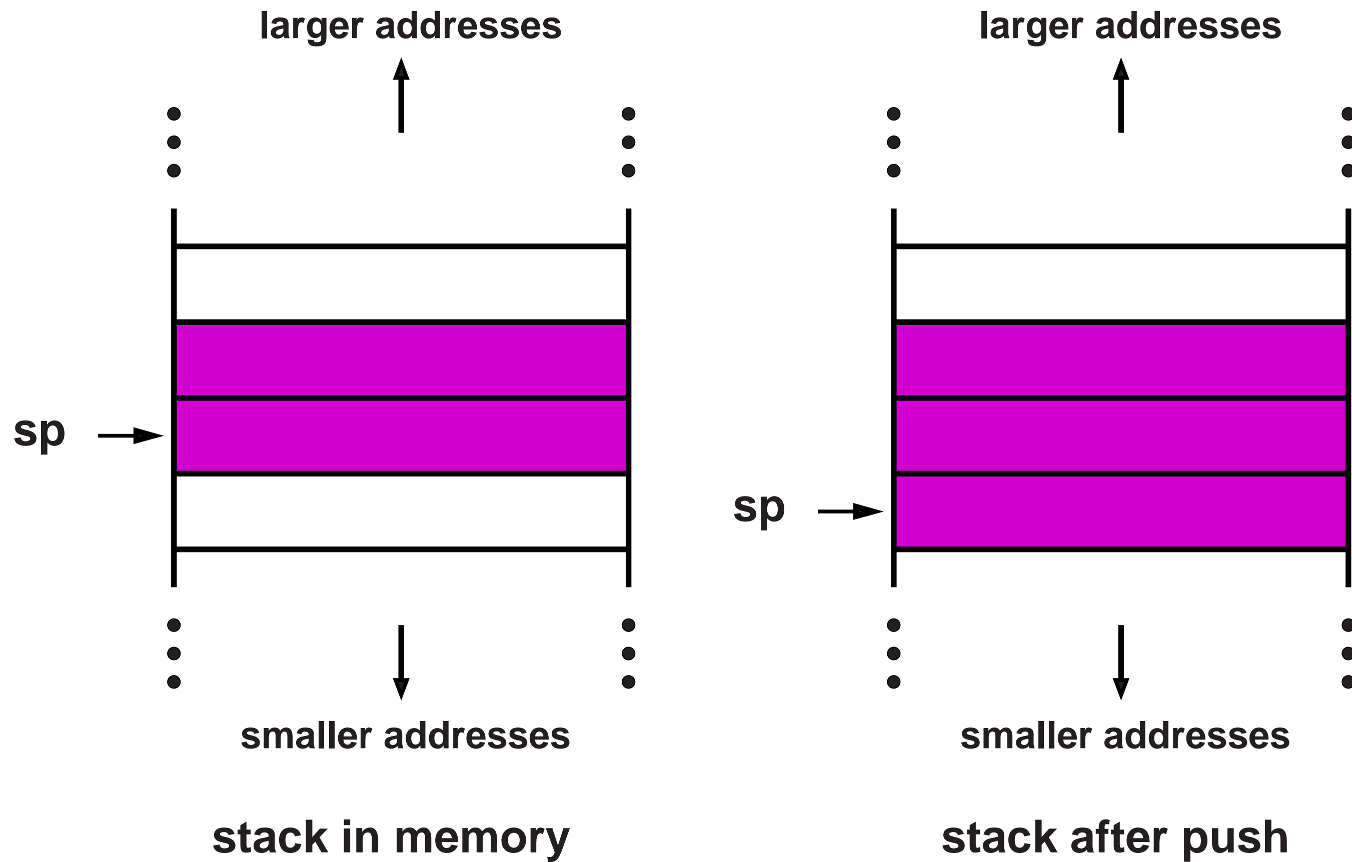
```
int NumSpaces (char *s)
{
  int count;
  if (!(*s)) return 0;
  count = NumSpaces (s+1);
  if (*s == ' ') count++;
  return count;
}
```

see also: Recursion

What About Recursion?

```
NumSpaces:  addu $17,$0,$4        # s = argument1
            lbu $8, 0($17)        # temp = *s
            beq $8,$0,$done       # if *s == 0 goto done
            addiu $4,$4,1         # argument = s+1
            jal NumSpaces         # call NumSpaces
                                  # count is $2
            li $9,32              # temp = ' '
            bne $9,$8,$skipinc    # if *s != ' '
                                  #  goto skipinc
            addiu $2,$2,1         # count++
 $skipinc:  jr $31                # return
    $done:  li $2,0               # return value = 0
            jr $31                # return
```

Stacks: Last-In First-Out



- Push: save a value/add entry
- Pop: restore a value/remove entry

Stacks

- Use stack to save return address, registers
- Stack pointer: register 29 (what's push/pop?)
- Stack frames
  - Groups of elements pushed/popped for a single call

Once again...

start executing the function?	use `jal`, but save return address on stack
return from the function?	use `jr`, but pop return address first

Third Attempt

```
NumSpaces:  addiu $29,$29,-4     # allocate stack space
            sw $31,0($29)        # save return addr
            addu $17,$0,$4       # s = argument0
            lbu $8, 0($17)       # temp = *s
            beq $8,$0,$done      # if (temp == 0) goto done
            addiu $4,$4,1        # argument0 = s+1
            jal NumSpaces        # recursive call
            li $9,32             # temp2 = ’ ’
            bne $9,$8,$skipinc   # if (temp != ’ ’) goto skipinc
            addiu $2,$2,1        # count++
  $skipinc  lw $31,0($29)        # pop return address
            addiu $29,$29,4      # pop stack
            jr $31               # return
    $done:  li $2,0              # return val = 0
            lw $31,0($29)        # pop return address
            addiu $29,$29,4      # pop stack
            jr $31               # return
```

Fourth Attempt

Register usage convention:

- Who saves registers?
  - Caller vs callee
- Where are the registers saved?
  - Must be in memory
  - Stack!
- Which registers should be saved?
  - In general, all those ones that are modified...

(FORTRAN 77 does not support recursion, saves variables in globals)

Fourth Attempt

Example: a function that modifies `$8,$9,$18`

```
Function:  addiu $29,$29,-16  # create space on stack
           sw $31,12($29)     # save ret addr
           sw $8, 8($29)      # save $8
           sw $9, 4($29)      # save $9
           sw $18, 0($29)     # save $18
           ...
    $ret:  lw $18,0($29)      # restore $18
           lw $9,4($29)       # restore $9
           lw $8,8($29)       # restore $8
           lw $31,12($29)     # restore ret addr
           addiu $29,$29,16   # pop stack
           jr $31             # return
```

Prolog and Epilog

Functions are assembled in a standard form:

- Prolog
  - Template code at the beginning
  - Allocates space on the stack, saves registers
- Epilog
  - Template code at the end
  - Deallocates space on the stack, restores registers

Problem: too much call/return overhead.

MIPS Calling Convention

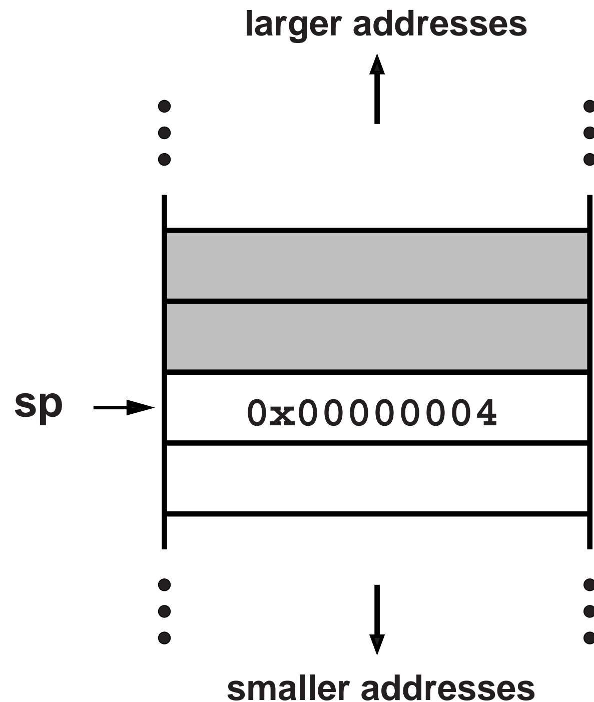
- First 4 integer arguments: $4–$7 ($a0–$a3)
- Return address: $31 ($ra)
- Stack pointer: $29 ($sp)
- Frame pointer: $30 ($fp)
- Return value: $2, $3 ($v0,$v1)
- Callee saved: $16–$23 ($s0–$s7)
- Caller saved: $8–$15,$24,$25 ($t0–$t7,$t8,$t9)
- Reserved: $26,$27 ($k0,$k1)
- Global pointer: $28 ($gp)
- Assembler temporary: $1 ($at)

Argument Passing

What if there are >4 arguments?

Use the stack.

```
void f(int a, int b, int c, int d, int e) { ...  }
```




```
li $4,0              # arg0 = 0
li $5,1              # arg1 = 1
li $6,2              # arg2 = 2
li $7,3              # arg3 = 3
li $8,4              # temp = 4
sw $8,-4($29)        # arg4 = 4
addiu $29,$29,-4     # on stack
jal f
```

Argument Passing

How do we handle variable-length parameters?

Example:

```
printf ("Avg:%f, Mean:%f, Med:%f\n",x,y,z);
```

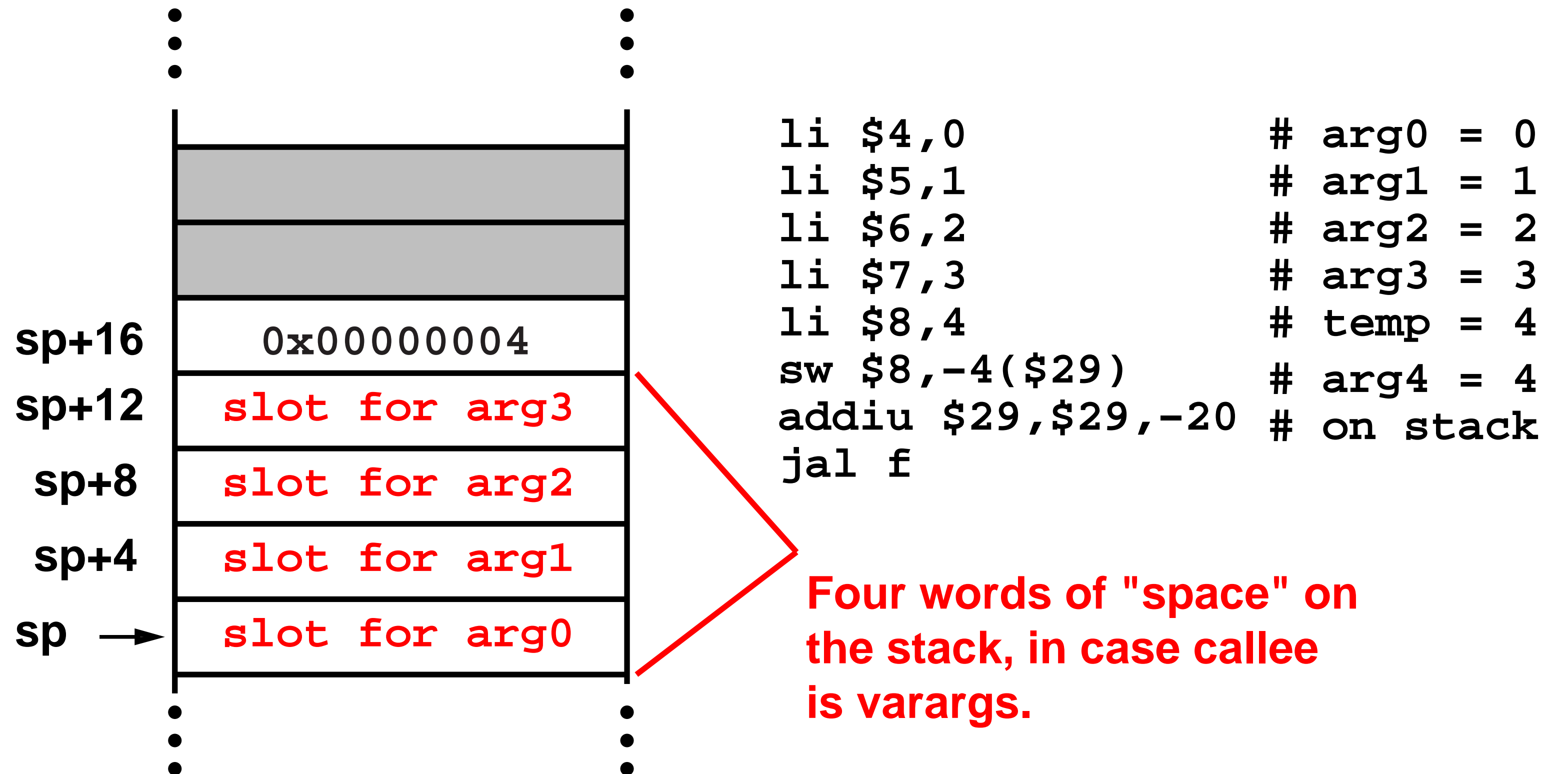
- Special-purpose code?

```
if (num == 1) use $4; else if (num == 2) use $5;
...
```

- Put all arguments on stack?
- MIPS: leave space on the stack for 4 args
  - caller may not know function is varargs
  - callee can copy args to stack if necessary

Argument Passing

```
void f(int a, int b, int c, int d, int e) { ...  }
```



... what about bytes/half-words/double-words?

Argument Passing

Body of function `f`:

Stack
(shaded)
(shaded)
0x00000004
slot for arg3
slot for arg2
slot for arg1
slot for arg0
saved $31
saved $28

sp+24 → 0x00000004; sp → saved $28; return address → saved $31

```
f:  addiu $29,$29,-8
    sw $31,4($29)
    sw $28,0($29)

    ...
```

What Else Goes On The Stack?

⋮
saved regs
arguments
standard saved regs
local variables
saved regs
arguments
standard saved regs
local variables
⋮

stack used by f1. f1 calls f2. (saved regs, arguments)

stack used by f2. f2 calls f3. (standard saved regs, local variables, saved regs, arguments)

stack used by f3. (standard saved regs, local variables)

- Local variables that don't fit in regs.
- Saved registers

Stack Frames

Register \$30 is the frame pointer.

- Value of stack pointer at function entry
- Used to restore stack pointer before returning

Part of stack owned by a function is the frame.

Frame pointers not really required. Needs to be saved/restored if used.