Procedure Calling

- Steps required
  1. Place parameters in registers
  2. Transfer control to procedure
  3. Acquire storage for procedure
  4. Perform procedure’s operations
  5. Place result in register for caller
  6. Return to place of call

Register Usage

- $a0 – $a3: arguments (reg's 4 – 7)
- $v0, $v1: result values (reg's 2 and 3)
- $t0 – $t9: temporaries
  - Can be overwritten by callee
- $s0 – $s7: saved
  - Must be saved/restored by callee
- $gp: global pointer for static data (reg 28)
- $sp: stack pointer (reg 29)
- $fp: frame pointer (reg 30)
- $ra: return address (reg 31)

Procedure Call Instructions

- Procedure call: jump and link

  ```
  jal ProcedureLabel
  ```

  - Address of following instruction put in $ra
  - Jumps to target address
- Procedure return: jump register

  ```
  jr $ra
  ```

  - Copies $ra to program counter
  - Can also be used for computed jumps
    - e.g., for case/switch statements

Leaf Procedure Example

- C code:

  ```
  int leaf_example (int g, h, i, j)
  { int f;
    f = (g + h) - (i + j);
    return f;
  }
  ```

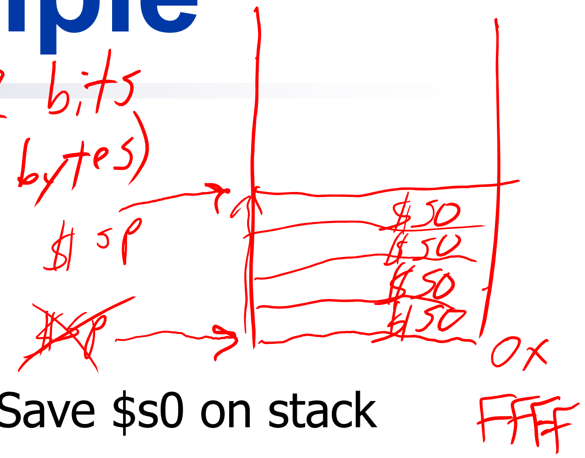
  - Arguments g, …, j in $a0, …, $a3
  - f in $s0 (hence, need to save $s0 on stack)
  - Result in $v0

Leaf Procedure Example

$s0 is 32 bits
(4 bytes)

- MIPS code:

```
leaf_example:
   addi $sp, $sp, -4
   sw   $s0, 0($sp)
   add  $t0, $a0, $a1
   add  $t1, $a2, $a3
   sub  $s0, $t0, $t1
   add  $v0, $s0, $zero
   lw   $s0, 0($sp)
   addi $sp, $sp, 4
   jr   $ra
```



Save $s0 on stack

Procedure body

Result

Restore $s0

Return

Non-Leaf Procedures

- Procedures that call other procedures
- For nested call, caller needs to save on the stack:
  - Its return address
  - Any arguments and temporaries needed after the call
- Restore from the stack after the call

Non-Leaf Procedure Example

- C code:

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

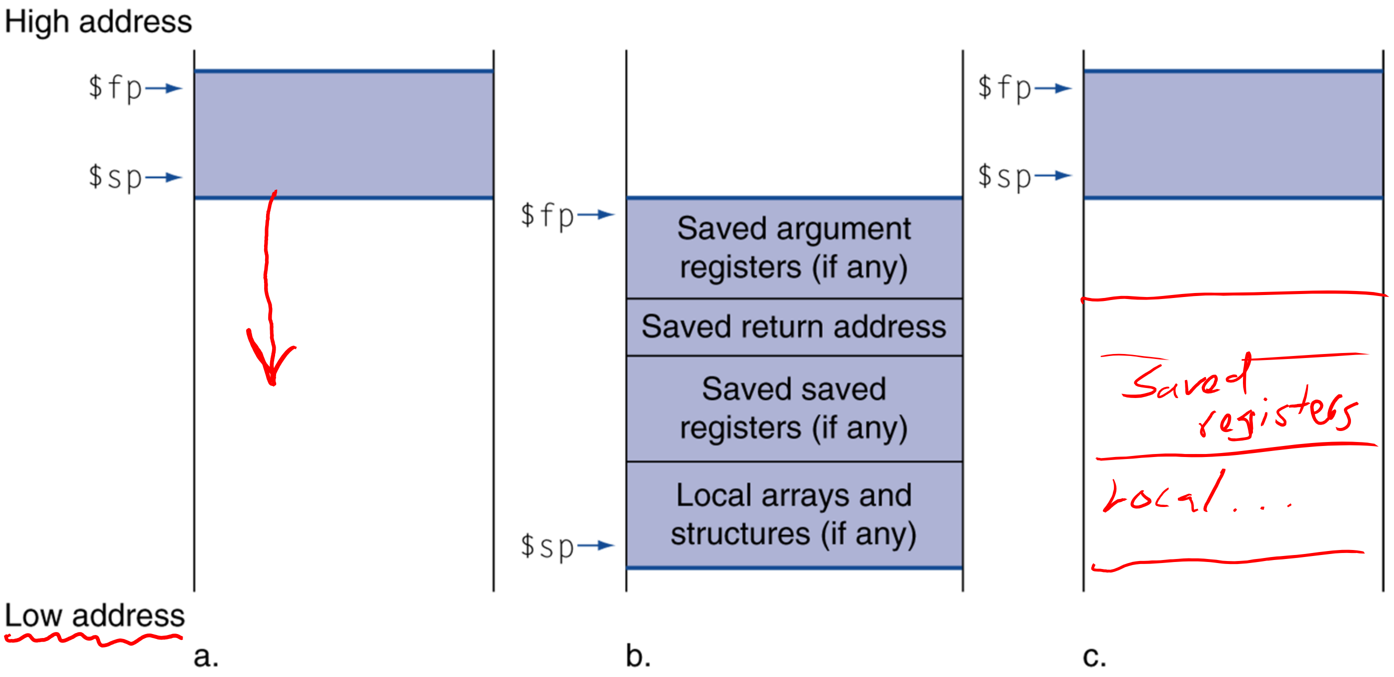
  - Argument n in $a0
  - Result in $v0

Non-Leaf Procedure Example

- MIPS code:

```
fact:
    addi $sp, $sp, -8     # adjust stack for 2 items
    sw   $ra, 0($sp)      # save return address
    sw   $a0, 4($sp)      # save argument
    slti $t0, $a0, 1      # test for n < 1
    beq  $t0, $zero, L1
    addi $v0, $zero, 1    # if so, result is 1
    addi $sp, $sp, 8      #   pop 2 items from stack
    jr   $ra              #   and return
L1: addi $a0, $a0, -1     # else decrement n
    jal  fact             # recursive call
    lw   $a0, 4($sp)      # restore original n
    lw   $ra, 0($sp)      #   and return address
    addi $sp, $sp, 8      # remove 2 items from stack
    mul  $v0, $a0, $v0    # multiply to get result
    jr   $ra              # and return
```

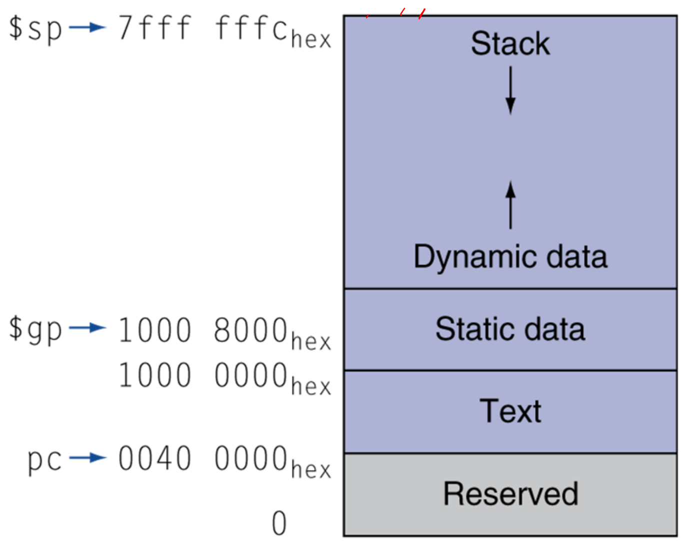
Local Data on the Stack


High address
$fp
$sp
$fp
Saved argument registers (if any)
Saved return address
Saved saved registers (if any)
Local arrays and structures (if any)
$sp
$fp
$sp
Saved registers
Local . . .
Low address
a.
b.
c.

- Local data allocated by callee
  - e.g., C automatic variables
- Procedure frame (activation record)
  - Used by some compilers to manage stack storage

Memory Layout

- Text: program code
- Static data: global variables
  - e.g., static variables in C, constant arrays and strings
  - $gp initialized to address allowing ±offsets into this segment
- Dynamic data: heap
  - E.g., malloc in C, new in Java
- Stack: automatic storage



Character Data

- Byte-encoded character sets
  - ASCII: 128 characters
    - 95 graphic, 33 control
  - Latin-1: 256 characters
    - ASCII, +96 more graphic characters
- Unicode: 32-bit character set
  - Used in Java, C++ wide characters, …
  - Most of the world’s alphabets, plus symbols
  - UTF-8, UTF-16: variable-length encodings

Byte/Halfword Operations

- Could use bitwise operations
- MIPS byte/halfword load/store
  - String processing is a common case

```
lb rt, offset(rs)      lh rt, offset(rs)
```

  - Sign extend to 32 bits in rt

```
lbu rt, offset(rs)     lhu rt, offset(rs)
```

  - Zero extend to 32 bits in rt

```
sb rt, offset(rs)      sh rt, offset(rs)
```

  - Store just rightmost byte/halfword