U. Wisconsin CS/ECE 552
Introduction to Computer Architecture

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Instructions (Chapter 2)

www.cs.wisc.edu/~karu/courses/cs552/

Slides combined and enhanced by Karu Sankaralingam from work by Falsafi, Hill, Marculescu, Nagle, Patterson, Roth, Rutenbar,Schmidt, Shen, Sohi, Sorin, Thottethodi, Vijaykumar, & Wood

Control Idiom: Pointer For Loop

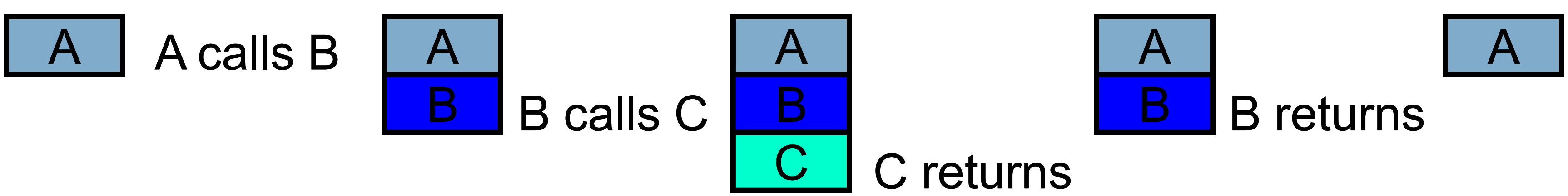
- Third idiom: **for loop with pointer induction**

```
struct node_t { int val; struct node_t *next; };
struct node_t *p, *head;
int sum;
for (p=head; p; p=p->next)     // p in $s1, head in $s2
    sum += p->val              // sum in $s3

          add $s1,$s2,$0       // p = head
    loop: beq $s1,$0,exit      // if p==0, goto exit
          lw $t1,0($s1)        // $t1 = *p = p→val
          add $s3,$s3,$t1      // sum = sum + p→val
          lw $s1,4($s1)        // p = *(p+1) = p→next
          j loop
    exit:
```

Control Idiom: Procedure Call

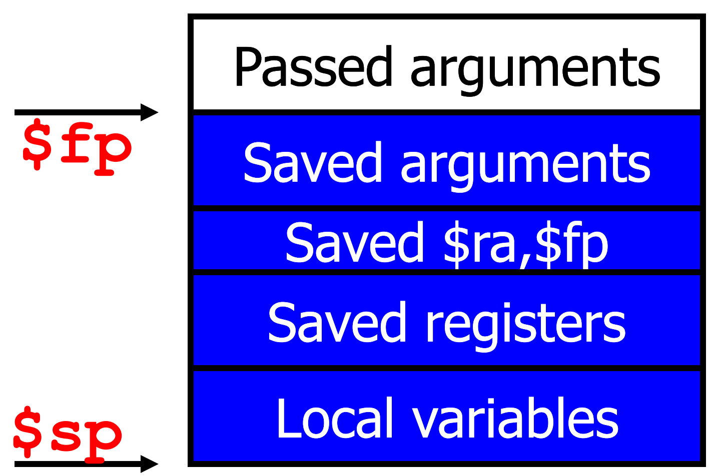
- In general, procedure calls obey **stack discipline**
  - Local procedure state contained in **stack frame**
  - When a procedure is called, a new frame opens
  - When a procedure returns, the frame collapses
- Procedure stack is **in memory**
  - Distinct from operand stack which is not addressable
- Procedure linkage **implemented by convention**
  - Called procedure ("callee") expects frame to look a certain way
    - Input arguments and return address are in certain places
  - Caller "knows" this



MIPS Procedure Calls

- Procedure stack implemented in software
  - No ISA support for frames: set them up with conventional stores
  - Stack is linear in memory and grows down (popular convention)
  - One register reserved for stack management
    - **Stack pointer** (`$sp=$29`): points to bottom of current frame
    - Sometimes also use **frame pointer** (`$fp=$30`): top of frame
      - Why? For dynamically variable sized frames
- Frame layout
  - Contents accessed using $sp

    `sw $ra,24($sp)`
  - Displacement addressing



MIPS Procedure Call: Factorial (Naïve version)

```
fact:   addi $sp,$sp,-128     // open frame (32 words of storage)
        sw $ra,124($sp)       // save all 32 registers
        sw $1,120($sp)
        sw $2,116($sp)
        …
        lw $s0,128($sp)       // read argument from caller's frame
        subi $s1,$s0,1
        sw $s1,0($sp)         // store (argument-1) to frame
        jal fact              // recursive call
        lw $s1,-4($sp)        // read return value from frame
        mul $s1,$s1,$s0       // multiply
        …
        lw $2,116($sp)        // restore all 32 registers
        lw $1,120($sp)
        lw $ra,124($sp)
        sw $s1,124($sp)       // return value below caller's frame
        addi $sp,$sp,128      // collapse frame
        jr $ra                // return
```

Note: code ignores base case of recursion (should return 1 if arg==1)

MIPS Calls and Register Convention

- Some inefficiencies with basic frame mechanism
  - **Registers**: do all need to be saved/restored on every call/return?
  - **Arguments**: must all be passed on stack?
  - **Returned values**: are these also communicated via stack?
  - No, fix with **register convention**

    `$2-$3($v0-$v1)`: expression evaluation and return **v**alues

    `$4-$7($a0-$a3)`: function **a**rguments

    `$8-$15,$24,$25($t0-$t9)`: caller saved **t**emporaries

      - A saves before calling B only if needed after B returns

    `$16-$23($s0-$s7)`: callee **s**aved

      - A needs after B returns, B saves if it uses also
  - We'll discuss complete set of MIPS registers and conventions soon

MIPS Factorial: Take II (Using Conventions)

```
fact: addi $sp,$sp,-8       // open frame (2 words)
      sw $ra,4($sp)         // save return address
      sw $s0,0($sp)         // save $s0
      ...
      add $s0,$a0,$0        // copy $a0 to $s0
      subi $a0,$a0,1        // pass arg via $a0
      jal fact              // recursive call
      mul $v0,$s0,$v0       // value returned via $v0
      ...
      lw $s0,0($sp)         // restore $s0
      lw $ra,4($sp)         // restore $ra
      addi $sp,$sp,8        // collapse frame
      jr $ra                // return, value in $v0
```

+ Pass/return values via **`$a0-$a3`** and **`$v0-$v1`** rather than stack
+ Save/restore 2 registers (**`$s0,$ra`**) rather than 31 (excl. $0)

Control Idiom: Call by Reference

- Passing arguments
  - **By value**: pass contents [$sp+4] in $a0

```
int n;                    // n in 4($sp)
foo(n);
        lw $a0,4(sp)
        jal foo
```

  - **By reference**: pass address $sp+4 in $a0

```
int n;                    // n in 4($sp)
bar(&n);
        add $a0,$sp,4
        jal bar
```

Instructions and Pseudo-Instructions

- Assembler helps give compiler illusion of regularity
  - Processor does not implement **all** possible instructions
  - Assembler accepts all insns, but some are **pseudo-insns**
    - Assembler translates these into native insn (insn sequences)
  - MIPS example #1

```
sgt $s3,$s1,$s2  // set $s3=1 if $s1>$s2

slt $s3,$s2,$s1  // set $s3=1 if $s2<$s1
```

  - MIPS example #2

```
div $s1,$s2,$s3  // div puts result in $lo

div $s1,$s2,$s3   // put result in $lo
mflo $s1          // move it from $lo to $s1
```