ECE260: Fundamentals of Computer Engineering

Supporting Procedures in Computer Hardware

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What are Procedures?

- Come with many different names:
  - ***Subroutine*** – a repeatable piece of code that you can call by name
  - ***Procedure*** – a subroutine that doesn't return a value
    - May have side-effects that write to files, print to the screen, modify input values, etc.
  - ***Function*** – a subroutine that returns one or more output values based on one or more input values
    - Given some input, produces some output (similar to a mathematical function)
  - ***Method*** – a procedure or function that is executed in the context of an object-oriented class
    - May have side-effects that modify the state of the object

Why Use Procedures?

- Readability
  - Divide up large programs into smaller procedures
- Reusability
  - Call same procedure from many parts of code
  - Programmers can use each others' code
- Parameterizability
  - Same function can be called with different arguments/parameters at runtime to produce different output or side-effects
- Polymorphism (in OOP – C++/Java/etc.)
  - Behavior can be determined at runtime as opposed to compile time based on object type

Why Use Procedures? (continued)

- Scoping of variable names
  - Use locally scoped variable names that make sense in the context of the procedure
  - No need to keep track of ALL variable names throughout entire program

```
int x = 5;

int foo(int x) {
   return x + 1;
}

int bar(int y) {
   int x = 0;
   return foo(x) + y;
}

main() {
   foo(bar(x));
}
```

```
int x1 = 5;

int foo(int x3) {          // arg x3 shadows x1
   return x3 + 1;
}

int bar(int y) {
   int x2 = 0;             // local var x2 shadows x1
   return foo(x2) + y;
}

main() {
   foo(bar(x1));           // no local x, use x1
}
```

What's the Procedure?

- Main idea for procedures
  - Some main code routine ***M*** **calls** a procedure ***P***
  - ***P*** does some work, then **returns** to ***M***
    - Execution in ***M*** picks up where it left off prior to calling ***P***
    - i.e., execution continues at the instruction in ***M*** after the instruction that called ***P***

Using Procedures

- A “calling” program (***Caller***) must:
  - Provide procedure parameters
    - Put the arguments in a place where the procedure can access them
  - Transfer control to the procedure (i.e. jump to the procedure)
- A “called” procedure (***Callee***) must:
  - Acquire the hardware resources (i.e. registers) needed to perform the function
  - Perform the function
  - Place results in a place where the Caller can find them
  - Return control back to the Caller

Steps for Calling Procedure on MIPS

1. Place parameters in registers before calling so callee can access them (use \$a0 - \$a3)
2. Transfer control to procedure using special instruction
   - Use **jal** instruction … it saves a <u>return address</u> … more info coming soon
3. Acquire storage resources needed for the procedure
   - Must backup (and later restore) contents of any \$sX registers used in procedure
   - \$tX registers may be overwritten by subroutines … be careful
4. Perform procedure's operations
5. Place result in register where the caller can access it (use \$v0 - \$v1)
6. Return to place of call
   - Register \$ra contains return address

MIPS Registers (now with more info!)

- **MIPS architecture has a 32 × 32-bit register file (e.g. it has 32 32-bit registers)**

Register Number	Register Name	Use	
0	$zero	Constant value 0	
1	$at	Assembler temporary	**Not for you!**
2 - 3	$v0 - $v1	Procedure return values	**Callee puts return value here**
4 - 7	$a0 - $a3	Procedure arguments	**Caller puts arguments here**
8 - 15	$t0 - $t7	Temporary values	**Callee may overwrite these**
16 - 23	$s0 - $s7	Saved temporary values	**Must be saved by callee if used**
24 - 25	$t8 - $t9	More temporary values	**Callee may overwrite these**
26 - 27	$k0 - $k1	Reserved for OS	**Also, not for you!**
28	$gp	Global pointer	**Easy access to constants/globals**
29	$sp	Stack pointer	**Top of stack**
30	$fp	Frame pointer	**Points to local variables on stack**
31	$ra	Return Address	**Where to go when returning from procedure**

Another Important CPU Register – Program Counter

- Register that contains the address of the instruction currently being executed
  - Abbreviated as **PC** for Program Counter
  - Should always point to a memory address in the TEXT segment of memory
    - Side note: common security exploit forces PC to point to stack … this is **BAD**
  - After each instruction is executed, PC typically increments by 4 so it points to the next instruction
    - PC = PC + 4
    - Increments by 4 since instructions are 4 bytes each (32-bits)
  - PC can be set using branch and jump instructions in lieu of the typical +4 increment behavior
    - This is also how procedures are "called"

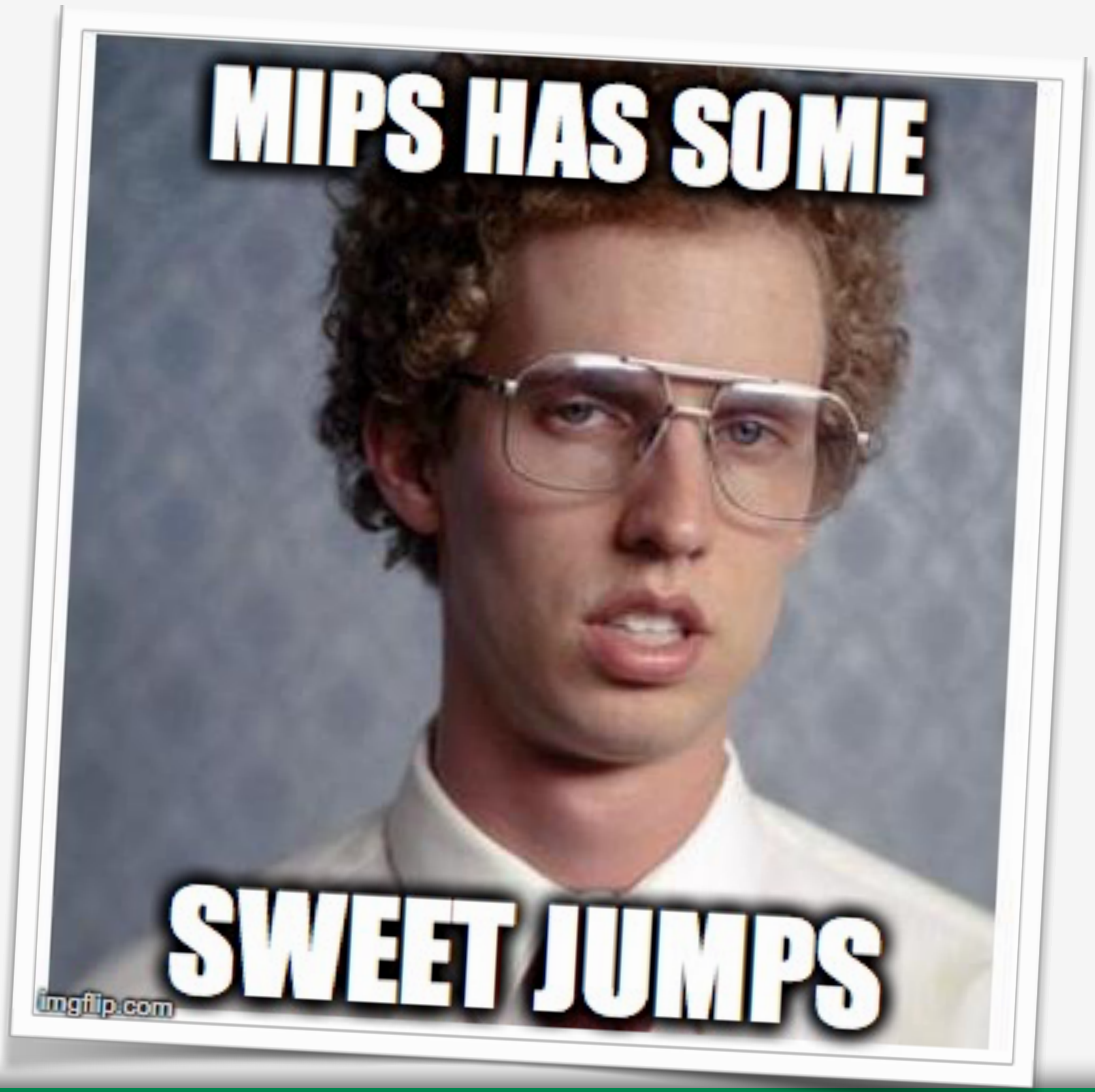
Procedure Call Instructions

- Jump-and-Link (jal) – a procedure call instruction
  - Address of instruction that immediately follows a jal is saved in \$ra (i.e. \$ra = PC + 4)
    - This is the return address … how the program returns to the Caller when Callee finishes
  - Jumps to target address (e.g. address of ProcedureLabel)

```
jal ProcedureLabel
```

- Jump Register (jr) – return from a procedure
  - Copies \$ra to program counter (i.e. PC = \$ra)
  - Can also be used for computed jumps (32-bit jump distance :-)
    - e.g. for case/switch statements

```
jr $ra
```



Leaf Procedure Example

- A ***leaf procedure*** is a procedure that does NOT call another procedure

- Example C code

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

- Assume the following:
  - Parameters g, h, i, j are passed in registers $a0, $a1, $a2, $a3
  - leaf_example code is called using a jal instruction that sets the $ra register
  - Plan to use register $s0 for local variable f
  - Must place return value in register $v0 when done

Leaf Procedure Example (continued)

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

```
leaf_example:
  addi $sp, $sp, –4        # plan to use $s0 locally, so make room on stack to save old $s0
  sw   $s0, 0($sp)         # store callers value of $s0 on stack ... will be restored later

  add  $t0, $a0, $a1       # $t0 = g + h
  add  $t1, $a2, $a3       # $t1 = i + j
  sub  $s0, $t0, $t1       # f = (g + h) – (i + j) ... recall f is stored in $s0

  add  $v0, $s0, $zero     # put f into special return value register $v0

  lw   $s0, 0($sp)         # before returning, restore callers value of $s0 from stack
  addi $sp, $sp, 4         # shrink stack to previous size (recall increasing $sp shrinks stack)

  jr   $ra                 # return to caller (instruction after jal instruction that called this)
```

Leaf Procedure Example (continued … maybe better)

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

For this example, no real need to use $s0, just put result directly into $v0 and skip the stack manipulation

```
leaf_example:
  addi $sp, $sp, -4         # plan to use $s0 locally, so make room on stack to save old $s0
  sw   $s0, 0($sp)          # store callers value of $s0 on stack ... will be restored later

  add  $t0, $a0, $a1        # $t0 = g + h
  add  $t1, $a2, $a3        # $t1 = i + j
  sub  $v0, $t0, $t1        # f = (g + h) – (i + j) ... put directly into $v0

  add  $v0, $s0, $zero      # put f into special return value register $v0

  lw   $s0, 0($sp)          # before returning, restore callers value of $s0 from stack
  addi $sp, $sp, 4          # shrink stack to previous size (recall increasing $sp shrinks stack)

  jr   $ra                  # return to caller (instruction after jal instruction that called this)
```