Lecture 6: Assembly Programs

- Today's topics:
  - Control instructions
  - Procedures
  - Examples

Control Instructions

- Conditional branch: Jump to instruction L1 if register1 equals register2:   beq   register1, register2, L1
  Similarly, bne and slt (set-on-less-than)

- Unconditional branch:
  j   L1
  jr $s0   (useful for big jumps and procedure returns)

Convert to assembly:

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if  (i == j)
    f = g+h;
else
    f = g-h;
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Convert to assembly:

```
if  (i == j)                  bne   $s3, $s4, Else
    f = g+h;                  add   $s0, $s1, $s2
else                          j     Exit
    f = g-h;           Else:  sub   $s0, $s1, $s2
                       Exit:
```

Example

Convert to assembly:

```
while   (save[i] == k)
      i += 1;
```

Values of i and k are in $s3 and $s5 and base of array save[] is in $s6

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```
Loop:  sll    $t1, $s3, 2
       add    $t1, $t1, $s6
       lw     $t0, 0($t1)
       bne    $t0, $s5, Exit
       addi   $s3, $s3, 1
       j      Loop
Exit:
```

```
       sll    $t1, $s3, 2
       add    $t1, $t1, $s6
Loop:  lw     $t0, 0($t1)
       bne    $t0, $s5, Exit
       addi   $s3, $s3, 1
       addi   $t1, $t1, 4
       j      Loop
Exit:
```

Registers

- The 32 MIPS registers are partitioned as follows:
  - Register 0 : $zero always stores the constant 0
  - Regs 2-3 : $v0, $v1 return values of a procedure
  - Regs 4-7 : $a0-$a3 input arguments to a procedure
  - Regs 8-15 : $t0-$t7 temporaries
  - Regs 16-23: $s0-$s7 variables
  - Regs 24-25: $t8-$t9 more temporaries
  - Reg 28 : $gp global pointer
  - Reg 29 : $sp stack pointer
  - Reg 30 : $fp frame pointer
  - Reg 31 : $ra return address

Procedures

- Local variables, AR, $fp, $sp
- Scratchpad and saves/restores
- Arguments and returns
- jal and $ra

Procedures

- Each procedure (function, subroutine) maintains a scratchpad of register values – when another procedure is called (the callee), the new procedure takes over the scratchpad – values may have to be saved so we can safely return to the caller
  - parameters (arguments) are placed where the callee can see them
  - control is transferred to the callee
  - acquire storage resources for callee
  - execute the procedure
  - place result value where caller can access it
  - return control to caller

Jump-and-Link

- A special register (storage not part of the register file) maintains the address of the instruction currently being executed – this is the *program counter* (PC)

- The procedure call is executed by invoking the jump-and-link (jal) instruction – the current PC (actually, PC+4) is saved in the register $ra and we jump to the procedure's address (the PC is accordingly set to this address)

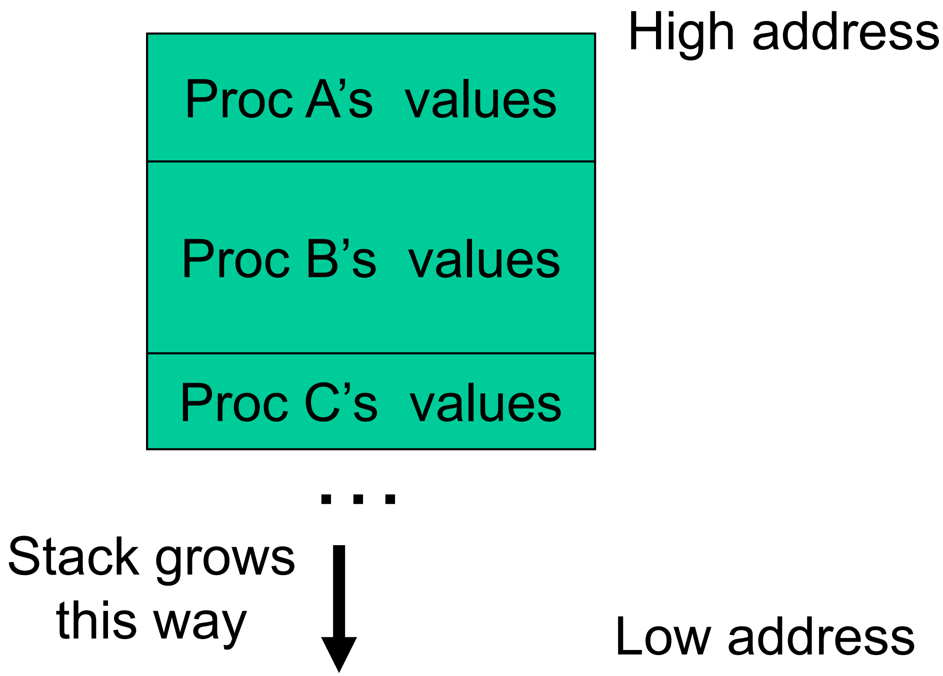
  jal   NewProcedureAddress

- Since jal may over-write a relevant value in $ra, it must be saved somewhere (in memory?) before invoking the jal instruction

- How do we return control back to the caller after completing the callee procedure?

The Stack

The register scratchpad for a procedure seems volatile – it seems to disappear every time we switch procedures – a procedure's values are therefore backed up in memory on a stack




```
Proc A

        call  Proc B
               …
               call Proc C
                  …
               return
        return
return
```

Saves and Restores

Storage Management on a Call/Return

- A new procedure must create space for all its variables on the stack
- Before/after executing the jal, the caller/callee must save relevant values in \$s0-\$s7, \$a0-\$a3, \$ra, temps into the stack space
- Arguments are copied into \$a0-\$a3; the jal is executed
- After the callee creates stack space, it updates the value of \$sp
- Once the callee finishes, it copies the return value into \$v0, frees up stack space, and \$sp is incremented
- On return, the caller/callee brings in stack values, ra, temps into registers
- The responsibility for copies between stack and registers may fall upon either the caller or the callee

Example 1 (pg. 98)

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

```
leaf_example:
    addi    $sp,  $sp,  -12
    sw      $t1, 8($sp)
    sw      $t0, 4($sp)
    sw      $s0, 0($sp)
    add     $t0, $a0, $a1
    add     $t1, $a2, $a3
    sub     $s0, $t0, $t1
    add     $v0, $s0, $zero
    lw      $s0, 0($sp)
    lw      $t0, 4($sp)
    lw      $t1, 8($sp)
    addi    $sp, $sp, 12
    jr      $ra
```

Notes:

In this example, the callee took care of saving the registers it needs.

The caller took care of saving its $ra and $a0-$a3.

Could have avoided using the stack altogether.

Saving Conventions

- Caller saved: Temp registers \$t0-\$t9 (the callee won't bother saving these, so save them if you care), \$ra (it's about to get over-written), \$a0-\$a3 (so you can put in new arguments)

- Callee saved: \$s0-\$s7 (these typically contain "valuable" data)

- Read the Notes on the class webpage on this topic

Example 2 (pg. 101)

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

```
fact:
    slti    $t0, $a0, 1
    beq     $t0, $zero, L1
      addi  $v0, $zero, 1
      jr    $ra
L1:
    addi    $sp, $sp, -8
    sw      $ra, 4($sp)
    sw      $a0, 0($sp)
    addi    $a0, $a0, -1
    jal     fact
    lw      $a0, 0($sp)
    lw      $ra, 4($sp)
    addi    $sp, $sp, 8
    mul     $v0, $a0, $v0
    jr      $ra
```

Notes:
The caller saves $a0 and $ra
in its stack space.
Temp register $t0 is never saved.