Lecture 6: Assembly Programs

- Today's topics:
  - Procedures
  - Examples

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

```
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:
```

Example

lw $t0, some reg ($t1) that has addr of save[i]

Convert to assembly:

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

addr of save[i] = addr of save[0] + 4i

= $s6 + 4 $s3 → $t1

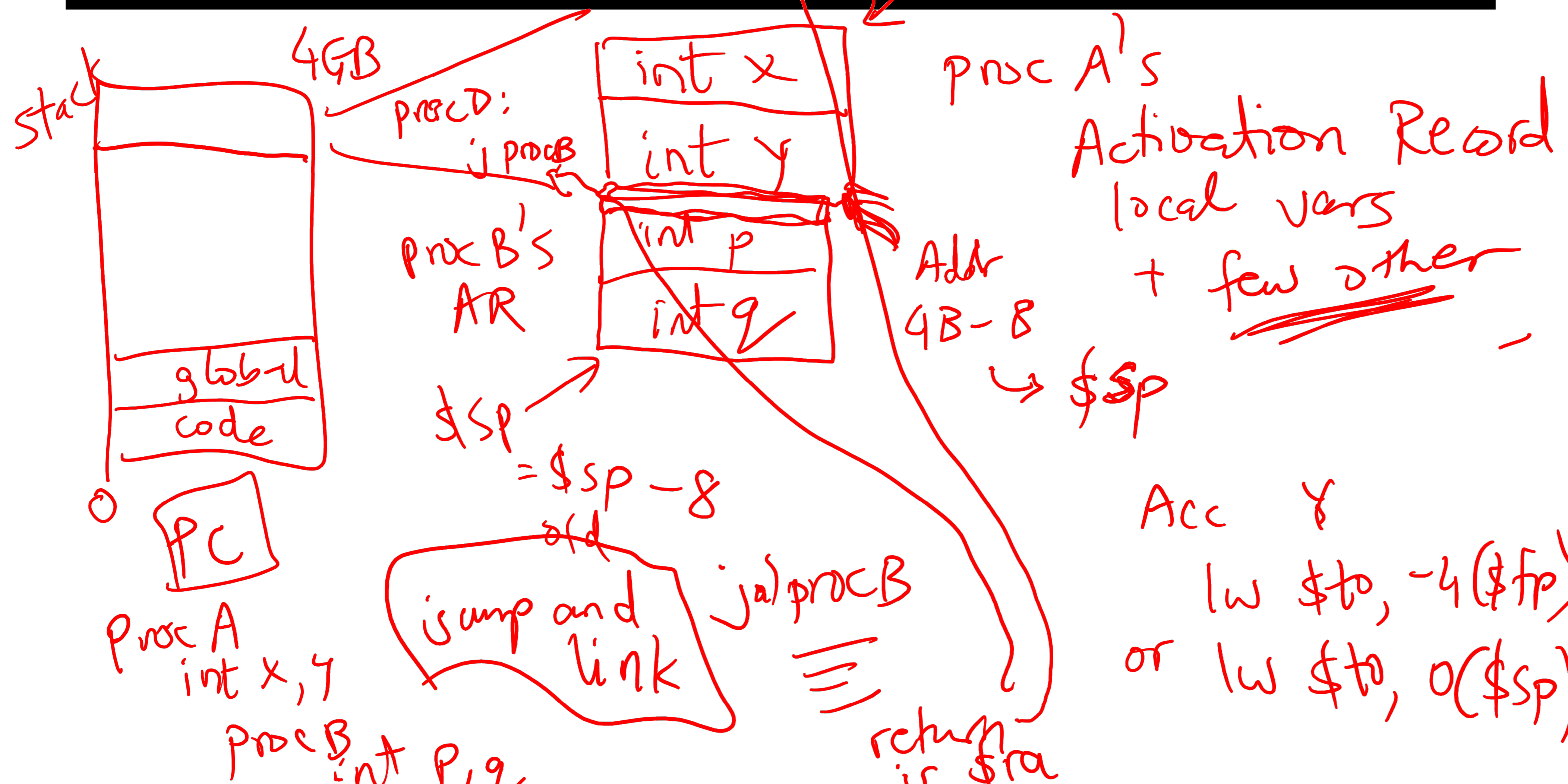
Values of i and k are in $s3 and $s5 and base of array save[] is in $s6 (address)

save[i] → $t0

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

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

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)

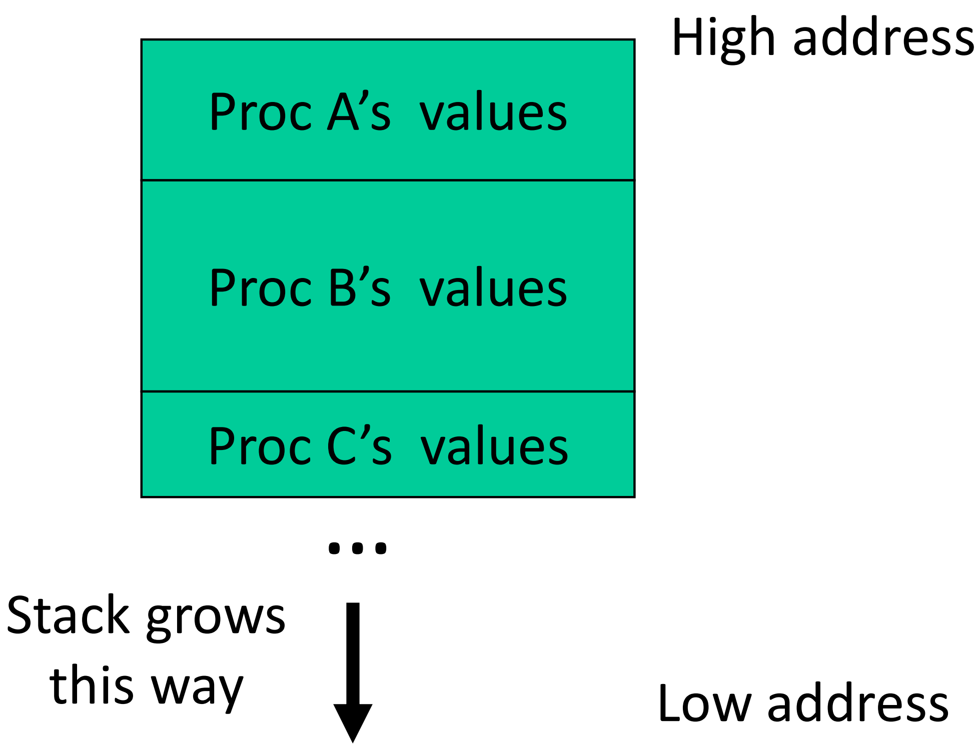
  jal NewProcedureAddress

- 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

Stack

procA

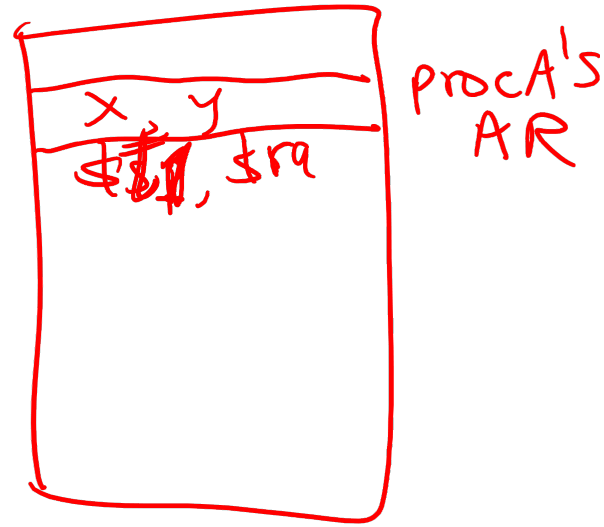
$t1 ← sw $ra, -4($sp)
sw $t1, 0($sp)
addi $sp, $sp, -8

jal procB

→ add $t3, $t1, $v0

return jr $ra

LIST:
$t1
$ra



restore – Mem
addi $sp, $sp, +8
lw $t1, 0($sp)
lw $ra, -4($sp)

procB:
⋮
jr $ra

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, $fp, 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

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

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), \$fp (if being used by the caller)

- 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.

slti

if ($a0 < 1)
then …
else …

Easier to implement with pseudo-instructions like blt, bge.

```
slti    $t0, $a0, 1           # if $a0 < 1, set $t0 = 1, else $t0 = 0
beq     $t0, $zero, else
then:
        …

else:
```