Lecture 6: Assembly Programs

- Today's topics:

  - Procedures
  - Examples

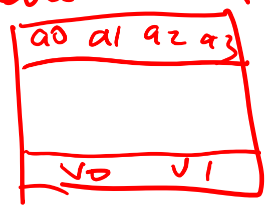
int x, y, z

Procedures

PC = 0
main
int a, b, c
procA
procB

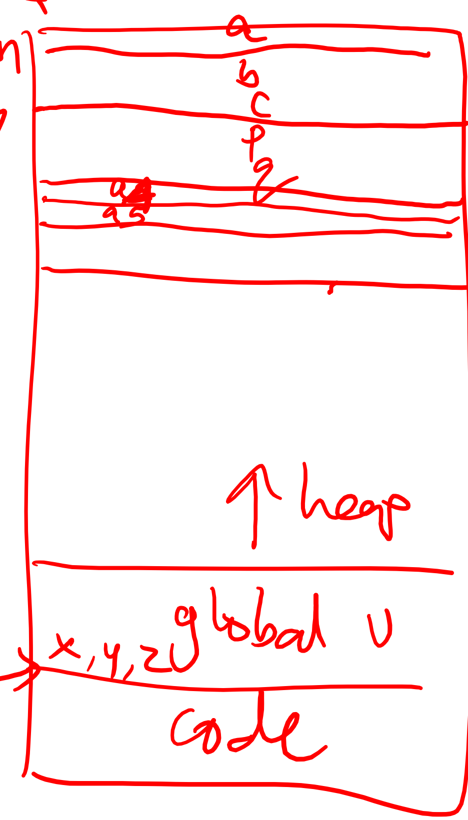
Act record

arguments →



reg file

$fp act record begins



lw $t1, 0($fp)
accesses p

lw $t2, 4($fp)
accesses q

PC = 3000
procA ( )
{ int p, q
procB ( )
}

PC = 5000
procB ( )
{ int i, j
}

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

Procedures

main

procA

procA

jal 440

jr $ra

0

72

140

72 PC program counter

$ra 76

$t1

$ra

fp

sp

i

j

$S3

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

procA

440

504 → jal ~~1084~~

ret ← 520

~~504~~ 1084 PC

76

508 $ra

main

fp →

a

b

c

procA

f

g

$t1

sp →

$ra 76

sp →

procB

1084

int i, j

jr $ra

```
addi $sp, $sp, 8
lw $t1, 0($sp)
lw $ra, -4($sp)
```

- 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

  a0 – a3

  - parameters (arguments) are placed where the callee can see them
  - control is transferred to the callee   jal
  - acquire storage resources for callee ⟹ AR   fp → sp →
  - execute the procedure
  - place result value where caller can access it   v0, v1
  - return control to caller   jr $ra

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

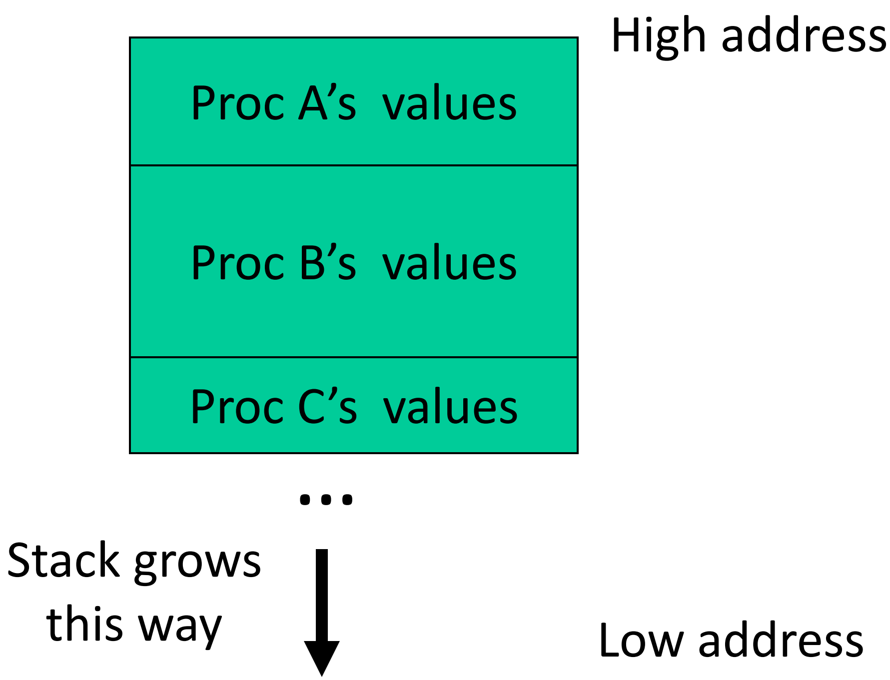
- Since jal may over-write a relevant value in $ra, it must be saved somewhere (in memory?) before invoking the jal instruction

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

~~jal~~ jr $ra

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, \$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 (and \$fp)
- 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)

Horrible code!

Callee

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

a0 a1 a2 a3

```
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
```

Saves

restores

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)

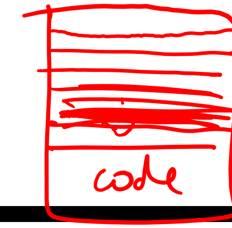
  If callee uses \$s3, it should first save the old value of \$s3

- Read the Notes on the class webpage on this topic main {

Example 2 (pg. 101) fact

}

slti



stack

```
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
```

if $n \geq 1$ jump to L1

if $n < 1$

saves

meat

restores

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

Dealing with Characters

- Instructions are also provided to deal with byte-sized and half-word quantities: lb (load-byte), sb, lh, sh

- These data types are most useful when dealing with characters, pixel values, etc.

- C employs ASCII formats to represent characters – each character is represented with 8 bits and a string ends in the null character (corresponding to the 8-bit number 0); A is 65, a is 97

Example 3 (pg. 108)

Convert to assembly:

```
void strcpy (char x[], char y[])
{
   int i;
   i=0;
   while  ((x[i] = y[i]) != `\0')
      i += 1;
}
```

```
strcpy:
  addi    $sp, $sp, -4
  sw      $s0, 0($sp)
  add     $s0, $zero, $zero
L1: add   $t1, $s0, $a1
  lb      $t2, 0($t1)
  add     $t3, $s0, $a0
  sb      $t2, 0($t3)
  beq     $t2, $zero, L2
  addi    $s0, $s0, 1
  j       L1
L2: lw    $s0, 0($sp)
  addi    $sp, $sp, 4
  jr      $ra
```

Notes:

Temp registers not saved.