aka MIPS Procedures

CS31

Pascal Van Hentenryck
MIPS Procedures

Functions in C, C++

Methods in Java

• A method is just a function with the receiver object as the first arguments

Outline

• Branching and return
• Passing arguments
• Saving registers
Procedures

Procedure without arguments

• Where to jump?
• Where to go back?

__start: move $s0,$s1
...
{call procedure gumbo}
mul $s2,$s5,$s7
...
done

gumbo: add $s3,$s4,$s5
...
{go back to where we came from}
The Kick

How do I go back now?

INCEPTION
Jumping and Kicking

MAL helps us quite a bit

jal label

• puts the address of the next instruction into register $ra (return address)
• branches to label

This is easy to do in hardware since the PC contains the right address (or almost)
Example Procedure

```assembly
__start:    li   $s0,7
            jal  verse1
            jal  refrain
            jal  verse2
            jal  refrain
            done
verse1:    ...
            ...
            jr   $ra
refrain:    ...
            ...
            jr   $ra
```

Could we do without jal?
Example Procedure

start:  li  $s0,7
        jal  verse1
        jal  refrain
        jal  verse2
        jal  refrain
        done

verse1:  ...
        jal  subverse1
        li  $s0,33
        jr  $ra

refrain:  ...
          ...
        jr  $ra

• What if verse1 does a jal?
• What if it uses $s0?
Example Procedure

start:    li   $s0,7
         jal  verse1
         jal  refrain
         jal  verse2
         jal  refrain
         done

verse1:  ...
         jal  subverse1
         li   $s0,33
         jr   $ra

• What if verse1 does a jal?

• What if it uses $s0?
Example Procedure

The 5 Levels Of **INCEPTION**

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<th>LEVEL</th>
<th>WHO DREAMED IT?</th>
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<th>WHY ARE THEY THERE?</th>
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<td>No one... We think</td>
<td>Cobb, Arthur, Ariadne, Eames, Saito, Yusuf and Robert Fischer Jr.</td>
<td>To drug Fischer Jr. and bring his subconscious into a dream.</td>
<td>There isn’t one. The timer counts down and the machine shuts off.</td>
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<td>Yusuf “The Chemist”</td>
<td>Cobb, Arthur, Ariadne, Eames, Saito, Yusuf and Robert Fischer Jr.</td>
<td>Fischer Jr. is kidnapped. They force him to give them random numbers which are used later, and begin planting the idea in his head that his father wants him to break up the company.</td>
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<td>No one In a shared state</td>
<td>Cobb, Ariadne, Saito, Robert Fischer Jr. and Mal’s projection</td>
<td>To get Fischer Jr. and Saito out.</td>
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The System Stack

(A Necessary Digression)

Sometimes we have to save data into memory:
• return addresses for nested procedures
• register values if more than one procedure wants to use the same register

It’s inconvenient to have to anticipate exactly how much such storage we’ll need and allocate memory to it explicitly.

Instead, we’ll construct another way to allocate memory locations: the system stack.
Stacks in the Abstract

Stacks have two operations:

• push(item): add item to the top of the stack
• pop: remove the item from the top of the stack

push a
push b
push c
pop =>
pop =>
push d
push e
pop =>
pop =>
pop =>
MIPS Stack

- the MIPS system stack is in memory (the same memory as your program and data)
- register $sp contains the stack pointer
- the stack grows in the direction of smaller addresses
- the stack pointer always contains the address of the next free location
Pushing

To push a word onto the stack:

```
sub $sp, $sp, 4
li $s0, 0x12345678
sw $s0, 4($sp)
```

Before:

```
$sp

33209872
```

After:

```
$sp

12345678  33209872
```
Popping

To pop a word off the stack:

\[
\begin{align*}
\text{lw} & \quad \text{\$s0, 4\ ($sp)} \\
\text{add} & \quad \text{\$sp, \$sp, 4}
\end{align*}
\]

Before:

\[
\begin{align*}
\text{$sp} & \quad \text{FAFAFAFA} \\
 & \quad 12121212 \\
 & \quad 34343434 \\
 & \quad 12345678
\end{align*}
\]

After:

\[
\begin{align*}
\text{$sp} & \quad \text{FAFAFAFA} \\
 & \quad 12121212 \\
 & \quad 34343434 \\
 & \quad 12345678
\end{align*}
\]
Saving Return Addresses

At the beginning of every procedure, push the return address on the stack. Then pop it at the end.

start:
   jal mumbo
   ...
   done
mumbo:
   sub $sp,$sp,4  # push ra
   sw $ra,4($sp)
   ...
   jal jumbo
   ...
   lw $ra,4($sp)  # pop ra
   add $sp,$sp,4
   jr $ra

Always do this!!
## Example Procedure

### The 5 Levels Of **INCEPTION**

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<td>To drug Fischer Jr. and bring his subconscious into a dream.</td>
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<td><strong>LEVEL 5</strong>- Limbo</td>
<td>No one... In a shared state</td>
<td>Cobb, Ariadne, Saito, Robert Fischer Jr. and Mal’s projection</td>
<td>To get Fischer Jr. and Saito out.</td>
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What is her name?
__start:
    lw     $t0, important_value
    jal    mumbo
    add    $t0, $t0, 1
...
done
S and T Registers

There are two sets of general-purpose registers:

  Saved registers:   $s0-$s8
  Temporary registers: $t0-$t9

Saved registers must be *preserved* across procedure calls, so if you use one in a procedure, you must restore its old value when you’re done.

Temporary registers may *not* be *preserved* across procedure calls.

What’s wrong with this picture?

```assembly
_start:
    lw     $t0, important_value
    jal    mumbo
    add    $t0,$t0,1
    ...
    done
```
Saving Registers

At the beginning of a procedure (after saving the return address) save any $s$ registers you are going to use. Restore them at the end.

# s1 will hold the GNP
# s2 will hold the avg. grease ratio
# t0 is used for calculation

jumbo:

```assembly
sub $sp, $sp, 4          # push ra
sw $ra, 4($sp)
sub $sp, $sp, 4
sw $s1, 4($sp)
sub $sp, $sp, 4
sw $s2, 4($sp)
...                      # do work
lw $s2, 4($sp)           # restore $s2
add $sp, $sp, 4
lw $s1, 4($sp)           # restore $s1
add $sp, $sp, 4
lw $ra, 4($sp)           # pop ra
add $sp, $sp, 4
jr $ra
```

Nobody said assembly language wasn’t tedious.
Saving Registers More Efficiently

We can make the previous example more efficient:

# s1: GNP
# s2: avg. grease ratio
# t0: used for calculation

jumbo:

```assembly
sub $sp,$sp,12
sw $ra,12($sp)  # push ra
sw $s1,8($sp)   # save s1
sw $s2,4($sp)   # save s2
...
lw $s2,4($sp)   # restore $s2
lw $s1,8($sp)   # restore $s1
lw $ra,12($sp)  # pop ra
add $sp,$sp,12
jr $ra
```
How to move data?

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Passing Arguments: The Easy Way

Registers $a0-$a3 are reserved for passing arguments. They are *not preserved* across procedure calls.

Registers $v0-$v1 are for returning results.

```assembly
# a0: one of the nums to be averaged
# a1: another num to be averaged
# v0: return the result
# t0: calculation

average:
  add $t0,$a0,$a1
  div $v0,$t0,2
  jr $ra
```

What if we need to call another procedure?
Passing Arguments: The General Way

In nested procedures, we may have to save argument values on the stack.

Sometimes, we’ll have too many arguments to fit into 4 registers, or too many return values.

General Answer: use the stack.
- Caller pushes arguments and space for results.
- Callee uses arguments and fills in results.
- Caller pops everything.
Arguments on the Stack

# average the values in $s0 and $s1, put the # result in $s2

sub     $sp,$sp,12       # space for rslt.
sw      $s0,8($sp)       # push 1st param
sw      $s1,12($sp)      # push 2nd param
jal     average
lw      $s2,4($sp)      # get result
add     $sp,$sp,12

done

average:

sub     $sp,$sp,4
sw      $ra,4($sp)
lw      $t0,12($sp)      # load 1st param
lw      $t1,16($sp)      # load 2nd param
add     $t0,$t0,$t1
div     $t0,$t0,2
sw      $t0,8($sp)      # store result
lw      $ra,4($sp)      # pop ra
add     $sp,$sp,4
jr      $ra            # return
# average the values in $s0 and $s1, put the
# result in $s2

```assembly
sub $sp,$sp,12  # space for rslt.
sw $s0,8($sp)   # push 1st param
sw $s1,12($sp)  # push 2nd param
jal average
lw $s2,4($sp)   # get result
add $sp,$sp,12
```
Arguments on the Stack

# average the values in $s0 and $s1, put the
# result in $s2

sub    $sp,$sp,12    # space for rslt.
sw     $s0,8($sp)    # push 1st param
sw     $s1,12($sp)   # push 2nd param
jal    average       # get result
lw     $s2,4($sp)
add    $sp,$sp,12
done   

average:
sub    $sp,$sp,4
sw     $ra,4($sp)

lw     $t0,12($sp)   # load 1st param
lw     $t1,16($sp)   # load 2nd param
add    $t0,$t0,$t1
div    $t0,$t0,2    # store result
lw     $ra,4($sp)   # pop ra
add    $sp,$sp,4
jr      $ra
Arguments on the Stack

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div   $t0,$t0,2
sw    $t0,8($sp)   # store result
lw    $ra,4($sp)   # pop ra
add   $sp,$sp,4
jr     $ra         # return
Stack Allocation

Where are these variables allocated?

```c
int fact(int n)
{
    if (n == 0)
        return 1;
    else {
        int f = fact(n-1);
        return n * f;
    }
}
```
Can we allocate an array on the stack?

```assembly
# size of the array in $s1
# address of the array will be in $s2

mult $t0,$s1,4
sub $sp,$sp,$t0
add $s2,$sp,4
```

How do I access the element i?

```assembly
mult $t1,"i",4
add $t1,$s2,$t1
lw $t0,($s2)
```

You can do that in C/C++?

```c
int* a = (int*) alloca(sizeof(int)*size);
```

What is the life time of this array?
Are we done?

“done” does not exist?
✓ just a short end for

jr $ra

But where are we jumping?