

CSCI 210: Computer Architecture

Lecture 12: Procedures

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Slides from Cynthia Taylor

Announcements

- Problem Set 3 due Today
- Problem Set 1 resubmit available _soon_
 - Due a week from when it's available
 - 25% of your grade comes from the original submission, 75% comes from the resubmission
- Lab 2 due Sunday
 - Make sure it runs on occs
- Office Hours Today 13:30 – 14:30

Jump and Link

`jal Label`

- Address of following instruction put in `$ra`
- Jumps to target address
- Used for procedure calls

Procedure Call Instructions

- Procedure call: jump and link

`jal ProcedureLabel`

- Address of following instruction put in `$ra`
- Jumps to target address

- Procedure return: jump register

`jr $ra`

- Copies `$ra` to program counter

Recall: Procedures

```
int addTimes3(int x, int y){  
    int w = y * 3;  
    int z = x + w;  
    return z;  
}
```

Procedure Calling

1. Place parameters in registers: \$a0, \$a1, \$a2, \$a3
2. Transfer control to procedure: jal label
3. Acquire storage for procedure: use the stack
4. Perform procedure's operations
5. Place result in register for caller: \$v0, \$v1
6. Return to place of call: jr \$ra

What does a procedure call look like?

...

```
move    $a0, $s2
```

```
jal     addTen
```

```
# Now v0 holds the value of $s2 + 10
```

...

```
addten:
```

```
addi    $v0, $a0, 10
```

```
jr      $ra
```

What is the problem with this code

```
move  $a0, $t2
move  $a1, $t3
jal   add
move  $t4, $v0
sub   $t4, $t4, $t2
```

```
#add  $a0,$a1
add:  add  $t2, $a0, $a1
      move $v0, $t2
      jr   $ra
```

A. Not adding correctly

D. There is nothing wrong with this code

B. \$t2 is overwritten in add

C. We are not saving the return address before the procedure

Saved temporaries?

- “Preserved” registers
 - You can trust them to persist past function calls
 - Functions must ensure not to change them or to restore them if they do
- Not “Preserved” registers
 - Contents can be changed when you call a function
 - If you need the value, you need to put it somewhere else

Aside: MIPS Register Convention

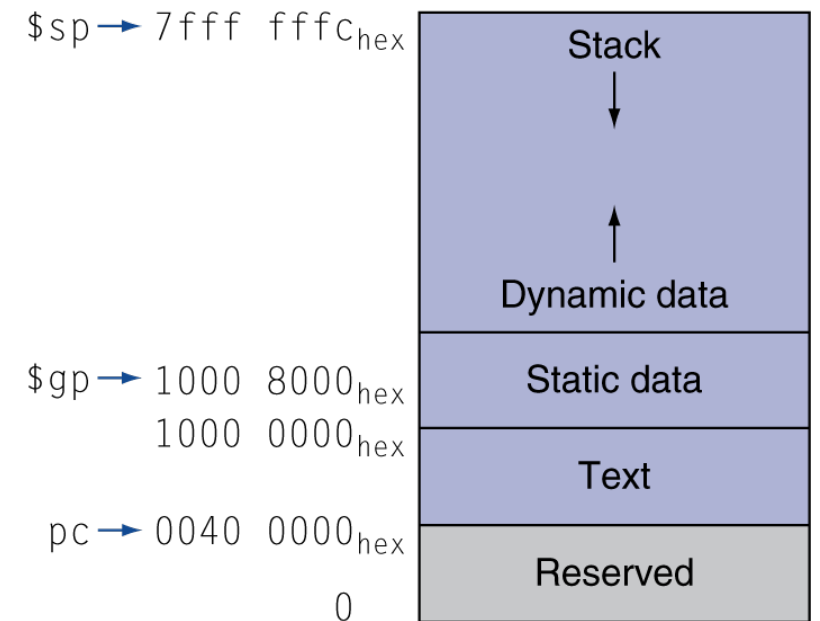
Name	Register Number	Usage	Preserve on call?
\$zero	0	constant 0 (hardware)	n.a.
\$at	1	reserved for assembler	n.a.
\$v0 - \$v1	2-3	returned values	no
\$a0 - \$a3	4-7	arguments	no
\$t0 - \$t7	8-15	temporaries	no
\$s0 - \$s7	16-23	saved values	yes
\$t8 - \$t9	24-25	temporaries	no
\$gp	28	global pointer	yes
\$sp	29	stack pointer	yes
\$fp	30	frame pointer	yes
\$ra	31	return addr (hardware)	yes

“Spill” and “Fill”

- Spill register **to** memory
 - Whenever you have too many variables to keep in registers
 - Whenever you call a method and need values in non-preserved registers
 - Whenever you want to use a preserved register and need to keep a copy
- Fill registers **from** memory
 - To restore previously spilled registers

Memory Layout

- Text: program code
- Static data: global variables
 - e.g., static variables in C, constant arrays and strings
 - \$gp initialized to address allowing \pm offsets into this segment
- Dynamic data: heap
 - E.g., malloc in C, new in Java
- Stack: automatic storage for procedures



Before and after a function

Assembly Code

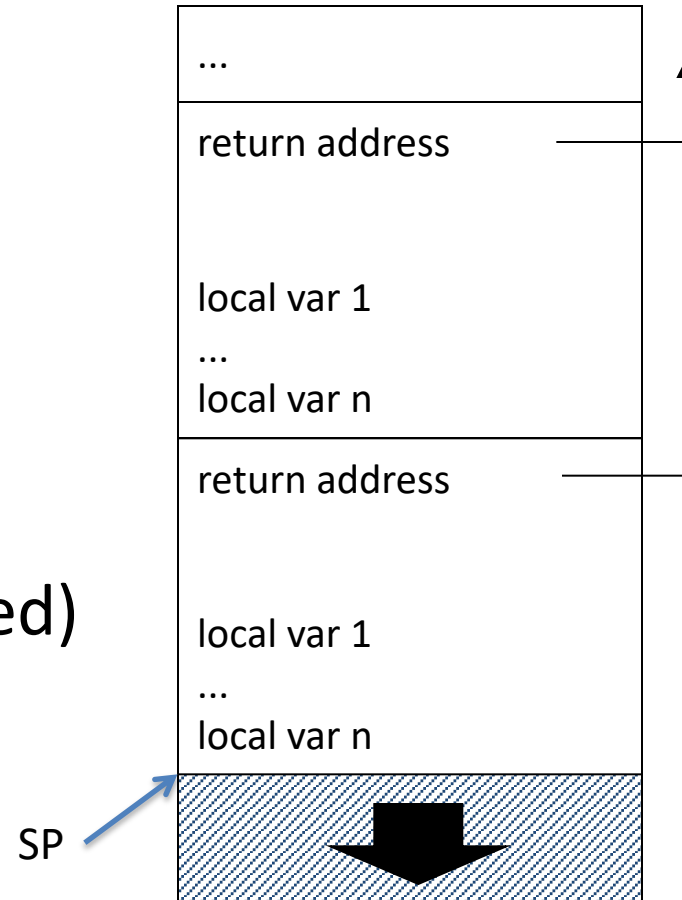
```
sw    $t0, 0($sp)
jal   myFunction
lw    $t0, 0($sp)
```

Which register is being spilled and filled?

- A. \$ra
- B. \$t0
- C. \$sp
- D. No register is spilled/filled
- E. No need to spill/fill any registers

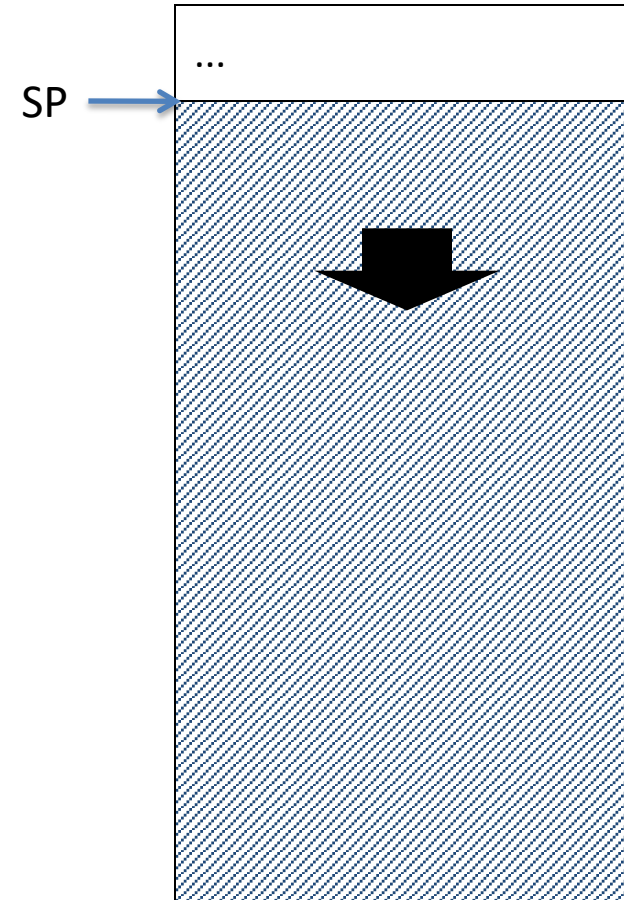
Stack

- Stack of stack frames
 - One per pending procedure
- Each stack frame stores
 - Where to return to
 - Local variables
 - Arguments for called functions (if needed)
- Stack pointer points to last record

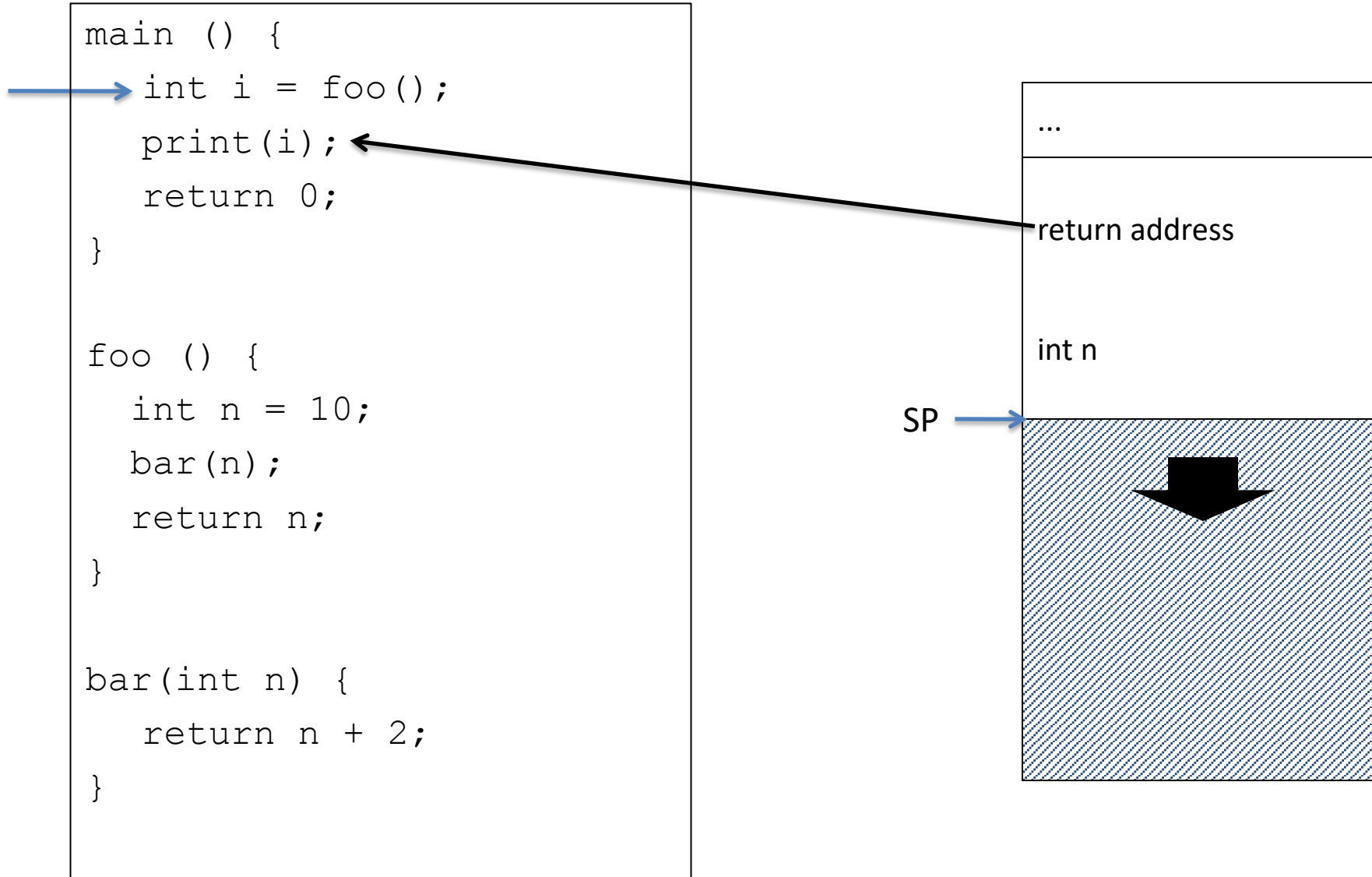


Process Stack

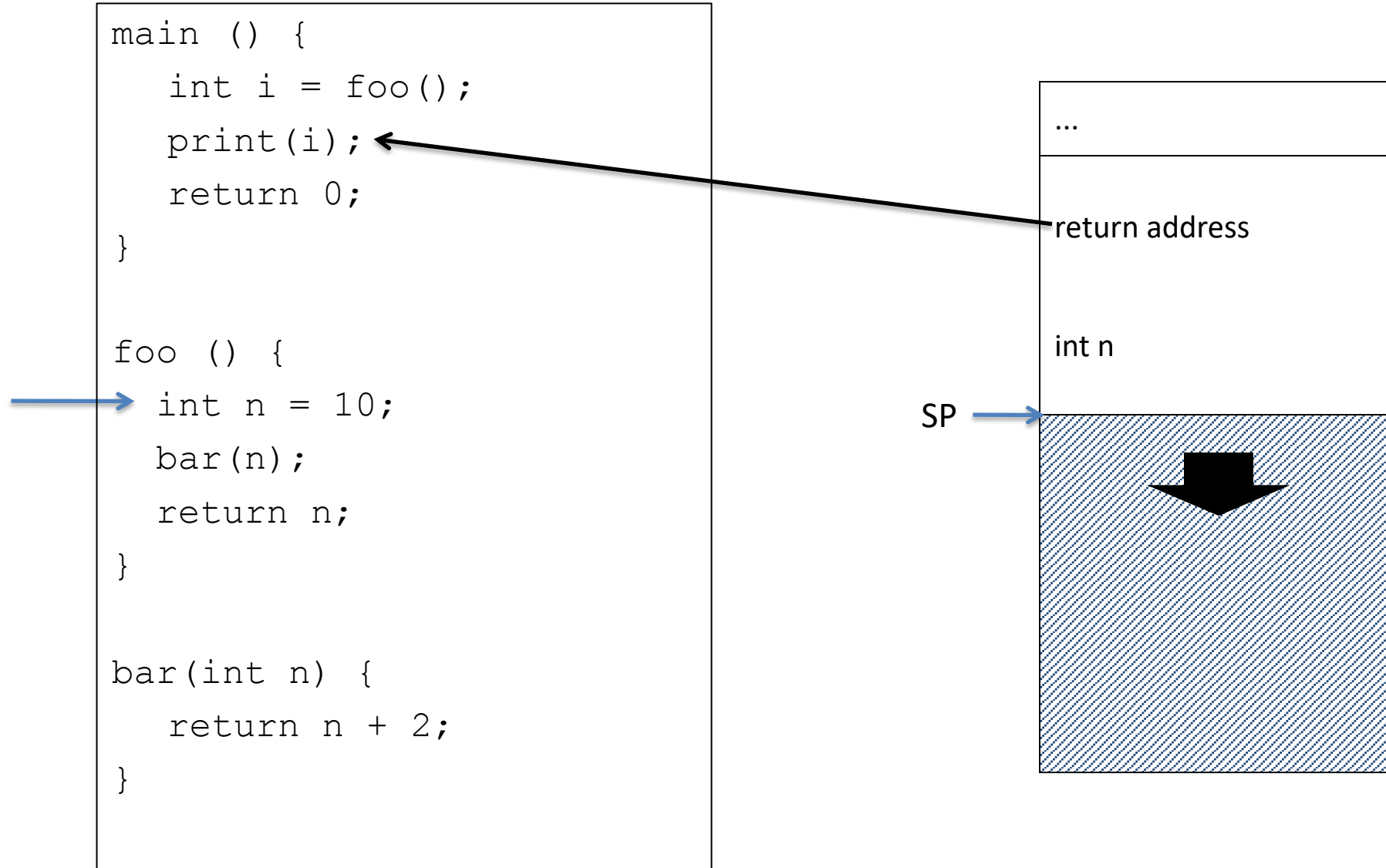
```
main () {  
    int i = foo();  
    print(i);  
    return 0;  
}  
  
foo () {  
    int n = 10;  
    bar(n);  
    return n;  
}  
  
bar(int n) {  
    return n + 2;  
}
```



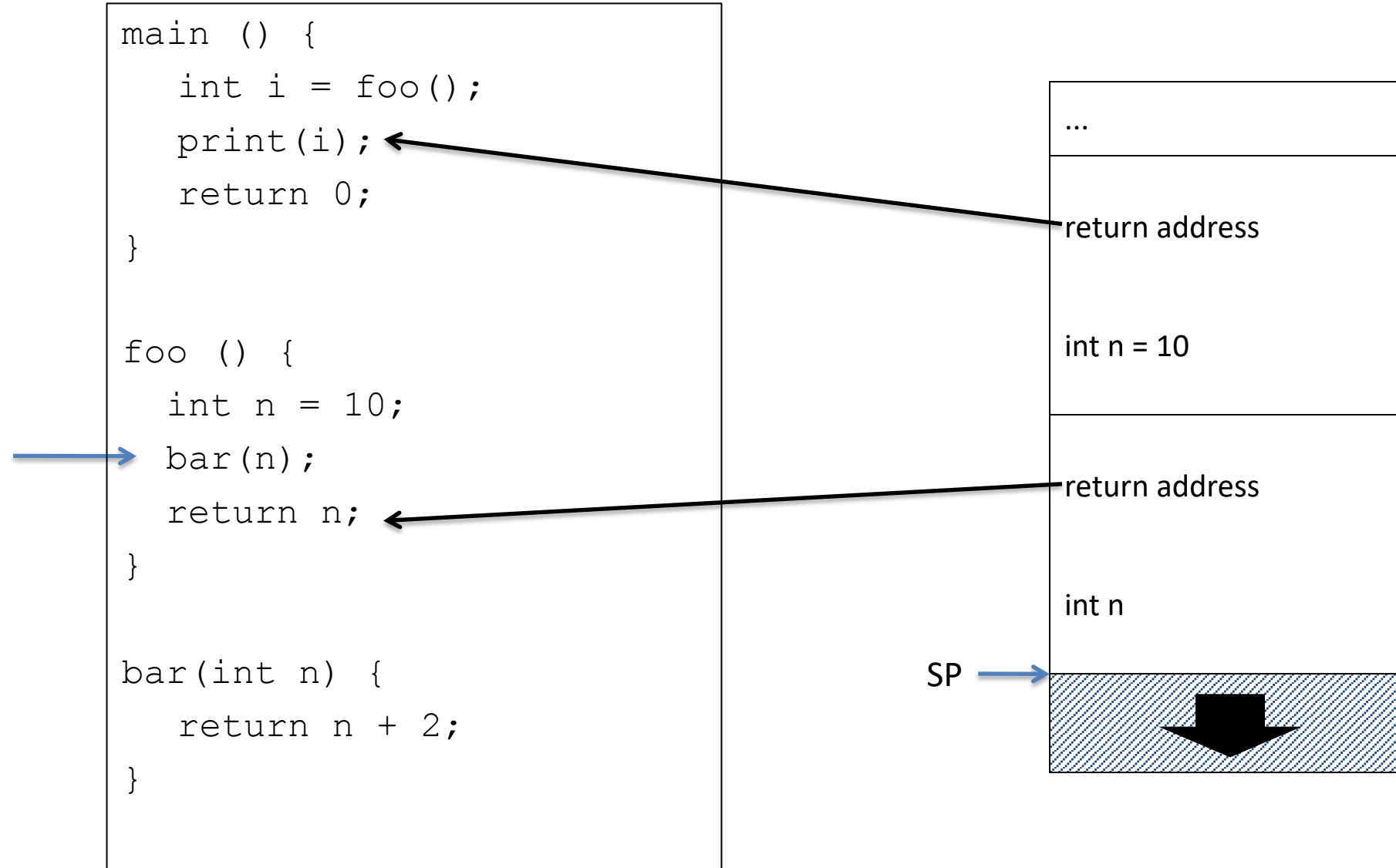
Process Stack



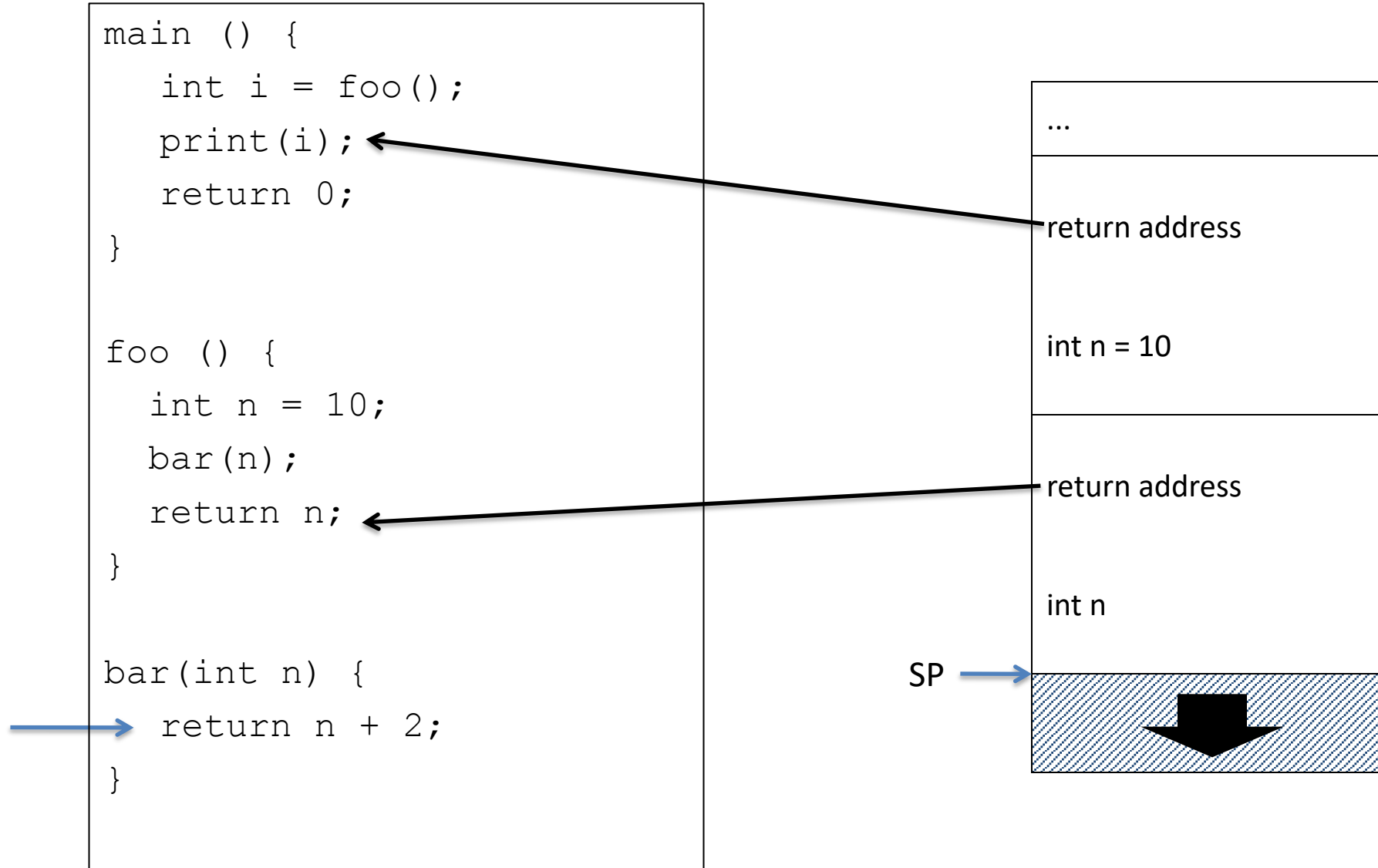
Process Stack



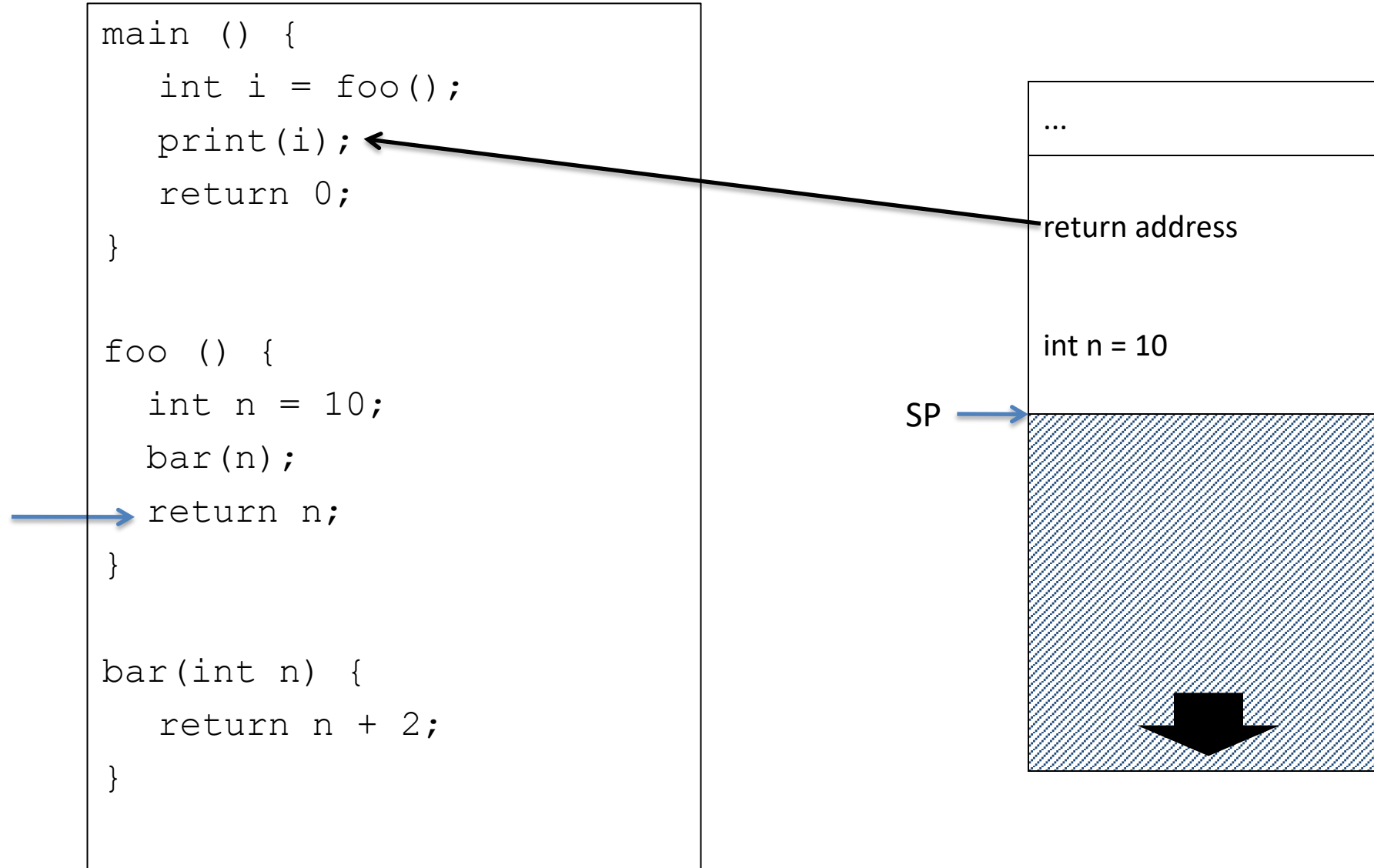
Process Stack



Process Stack

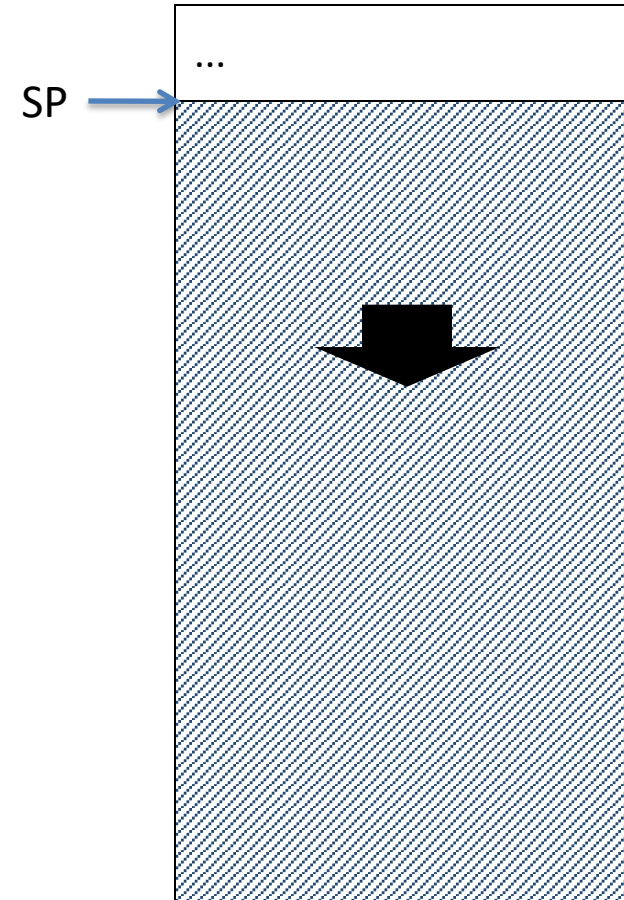


Process Stack



Process Stack

```
main () {  
    int i = foo();  
    print(i);  
    return 0;  
}  
  
foo () {  
    int n = 10;  
    bar(n);  
    return n;  
}  
  
bar(int n) {  
    return n + 2;  
}
```



To add a variable to the stack in MIPS

- Change the stack pointer `$sp` to create room on the stack for the variable
- Use `sw` to store the variable on the stack

Stack

If you wish to **push** an integer variable to the top of the stack, which of the following are true:

- A. You should decrement the stack pointer (\$sp) by 1
- B. You should decrement the \$sp by 4
- C. You do not have to do anything to \$sp
- D. You should increment the \$sp by 4
- E. None of the above

- To add the contents of \$s0 to the stack
 - addi \$sp, \$sp, -4
 - sw \$s0, 0(\$sp)
- To get the value back from the stack
 - lw \$s0, 0(\$sp)
- To “erase” the value from the stack
 - addi \$sp, \$sp, 4

To “spill” and “fill” a variable

```
addi $sp, $sp, -4  
sw $t0, 0($sp)  
jal myFunction  
lw $t0, 0($sp)  
addi $sp, $sp, 4
```

A better approach

- In the function “prologue,” reserve space on the stack for all of the variables and saved registers you’ll need
- Use `sw/lw` to spill and fill as needed to the space reserved in the prologue
- In the function “epilogue,” restore any saved registers you need and update the stack pointer

Complete example

foo:

```
addi    $sp, $sp, -12    # Reserve space for 3 vars
sw      $ra, 8($sp)      # Stores (spills) $ra, return address
sw      $s0, 4($sp)      # Stores (spills) s0, callee-saved reg
...
li      $s0, 25          # Set s0 to 25
sw      $t3, 0($sp)      # Stores (spills) t3, caller-saved reg
add     $a0, $t1, $t3
jal     myFunction
lw      $t3, 0($sp)      # Restores (fills) t3
...
lw      $s0, 4($sp)      # Restores (fills) s0, must restore
lw      $ra, 8($sp)      # Restores (fills) $ra, return address
addi    $sp, $sp, 12     # Restore the stack pointer
jr      $ra              # Return
```

Leaf function

- If the function doesn't call any other functions, it's a "leaf"
- If a leaf function doesn't need to use any of the callee-saved registers (e.g., \$s0–\$s7), then it doesn't need to change the stack pointer or spill/fill \$ra
- Example:

```
# myFunction(int a0, int a1, int a2)
```

```
myFunction:
```

```
    add    $t0, $a0, $a2
    sub    $v0, $t0, $a1
    jr     $ra
```

Reading

- Next lecture: More stack!
- Problem Set 3 due Today
- Lab 2 due Sunday