MIPS Calling Convention and the Call Stack

CS 64: Computer Organization and Design Logic
Lecture #10
Winter 2019

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Administrative

- Lab 5 this week

- You can review your midterm with a TA during office hours
  - *Last name*: **A thru L** **Bay-Yuan Hsu** **F 11 am – 1 pm**
  - *Last name*: **M thru Z** **Shiyu Ji** **F 3 pm – 5 pm**

- When reviewing your exams:
  - Do not take pictures, do not copy the questions
  - TA cannot change your grade
    - If you have a legitimate case for grade change, the prof. will decide
    - Legitimate = When we graded, we added the total points wrong
    - Not legitimate = Why did you take off *N* points on this question????

Lecture Outline

- MIPS Calling Convention
  - Function calling function example
  - Recursive function example

MIPS Call Stack

- We know what a Stack is…
- A **"Call Stack"** is used for storing ***the return addresses*** of the various **functions** which have been *called*

- When you **call** a function (e.g. **`jal funcA`**), the address that we need to return to is **pushed** into the call stack.

…

***funcA* does its thing… then…**

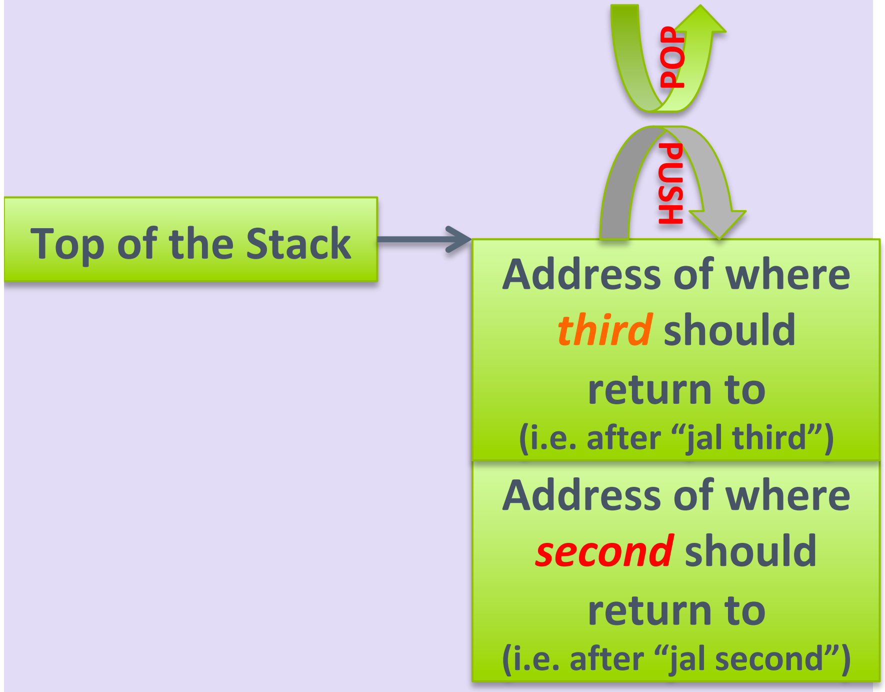
…

The function needs to return.

So, the address is **popped** off the call stack

MIPS Call Stack

```
void first()
{
    second()
    return; }

void second()
{
    third ();
    return; }

void third()
{
    fourth ();
    return; }

void forth()
{
    return; }
```



Top of the Stack

Address of where *third* should return to (i.e. after “jal third”)

Address of where *second* should return to (i.e. after “jal second”)

```
fourth:
    jr $ra

third:
    push $ra
    jal fourth
    pop $ra
    jr $ra

second:
    push $ra
    jal third
    pop $ra
    jr $ra

first:
    jal second

li $v0, 10
syscal
```

Why ***addiu?*** Because there is no such thing as a negative memory address **AND** we want to avoid triggering a processor-level ***exception on overflow***

```
fourth:
  jr $ra

third:
  addiu $sp, $sp, -4
  sw $ra, 0($sp)
  jal fourth
  lw $ra, 0($sp)
  addiu $sp, $sp, 4
  jr $ra

second:
  addiu $sp, $sp, -4
  sw $ra, 0($sp)
  jal third
  lw $ra, 0($sp)
  addiu $sp, $sp, 4
  jr $ra

first:
  jal second

li $v0, 10
  syscall
```

Pseudo-code

```
fourth:
  jr $ra

third:
  push $ra
  jal fourth
  pop $ra
  jr $ra

second:
  push $ra
  jal third
  pop $ra
  jr $ra

first:
  jal second

li $v0, 10
syscal
```

The MIPS Convention In Its Essence

- Remember: Preserved vs Unpreserved Regs
- **Preserved**: **$s0 - $s7**, and **$ra**, and **$sp (by default)**
- **Unpreserved**: **$t0 - $t9**, **$a0 - $a3**, and **$v0 - $v1**

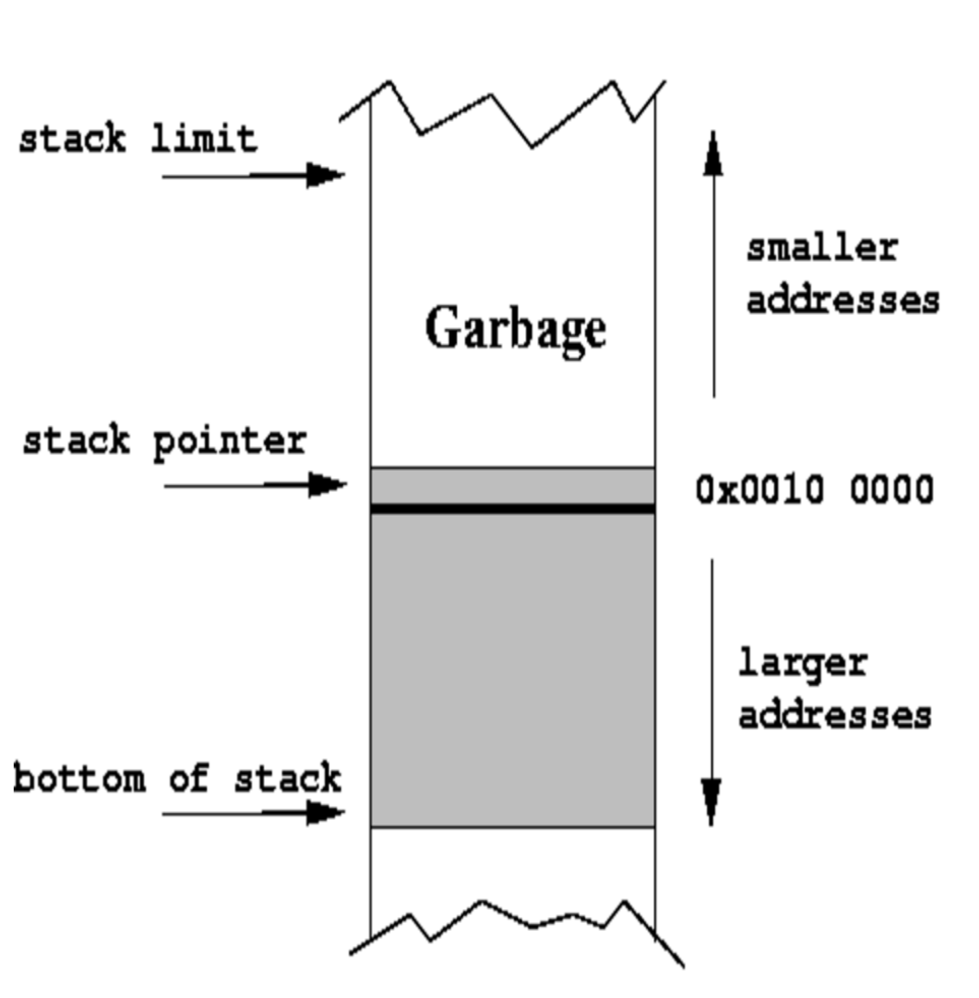
- Values held in **Preserved Regs** immediately before a function call MUST be the same immediately after the function returns.
- Values held in **Unpreserved Regs** must always be assumed to change after a function call is performed.
  - $a0 - $a3 are for passing arguments into a function
  - $v0 - $v1 are for passing values from a function

Reminder: How the Stack Works

- *Upon reset, $sp points to the "bottom of the stack" – the largest address for the stack*
  - *(0x7FFF FFFC, see MIPS RefCard)*

- *As you move $sp, it goes from high to low address*

- *The "top of the stack" is the stack limit*
  - *(0x1000 8000, see MIPS RefCard)*

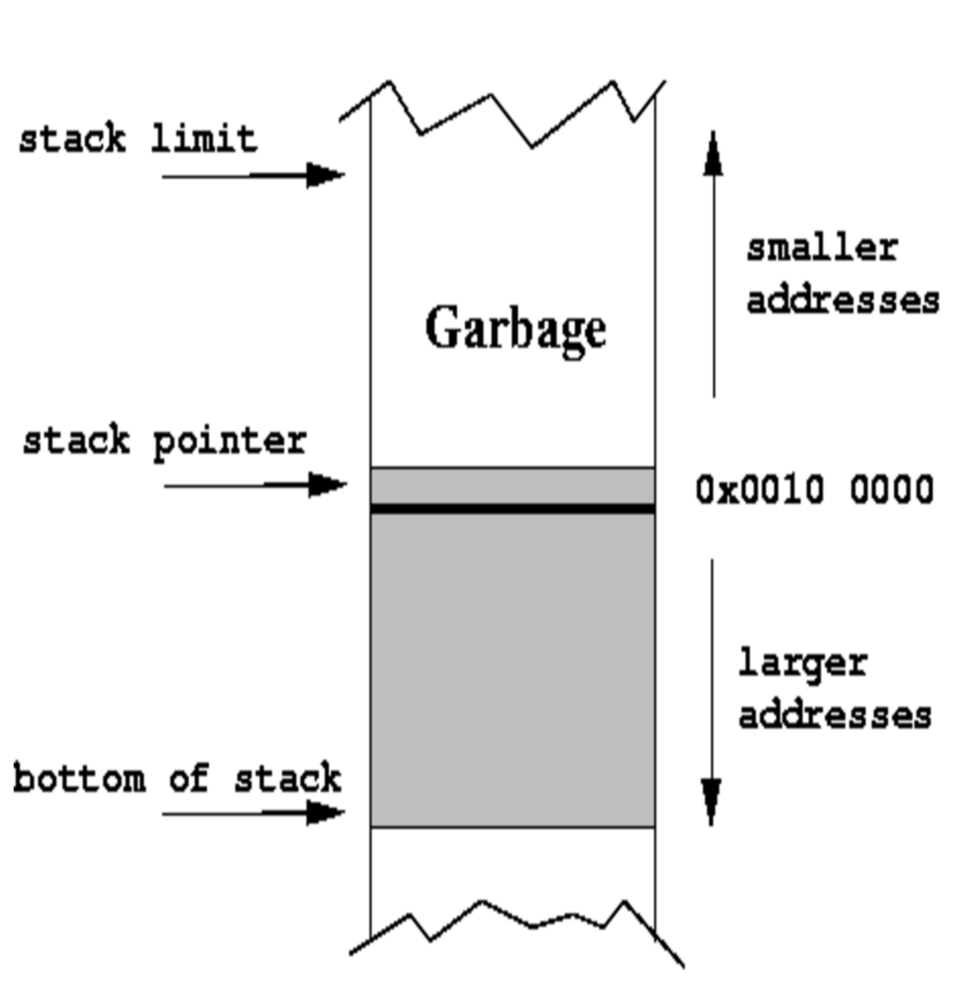


Reminder: How the Stack Works

- *When you want to store some N registers into the stack, the* ***convention*** *says you must:*

  A. *Make room in the stack (i.e. move $sp* ***4xN*** *places)*

  B. *Then store words accordingly*

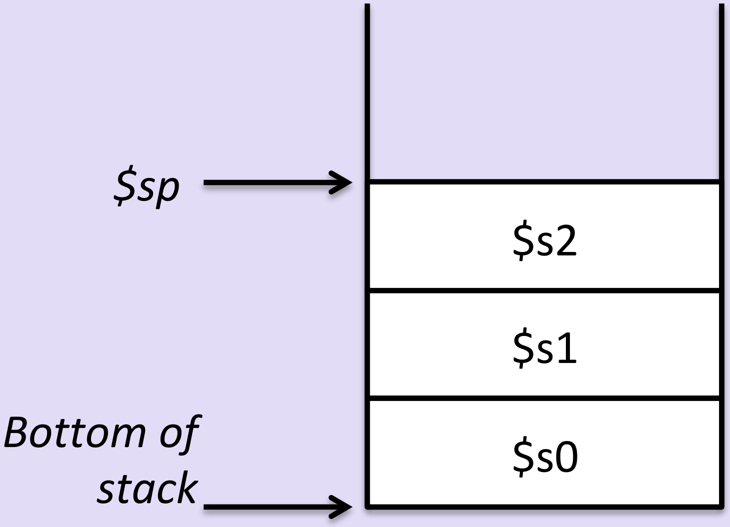


Reminder: How the Stack Works

Example:

You want to store $s0, $s1, and $s2:

```
addiu $sp, $sp, -12      # 'cuz 3 x 4 = 12
sw $s0, 8($sp)
sw $s1, 4($sp)
sw $s2, 0($sp)
```



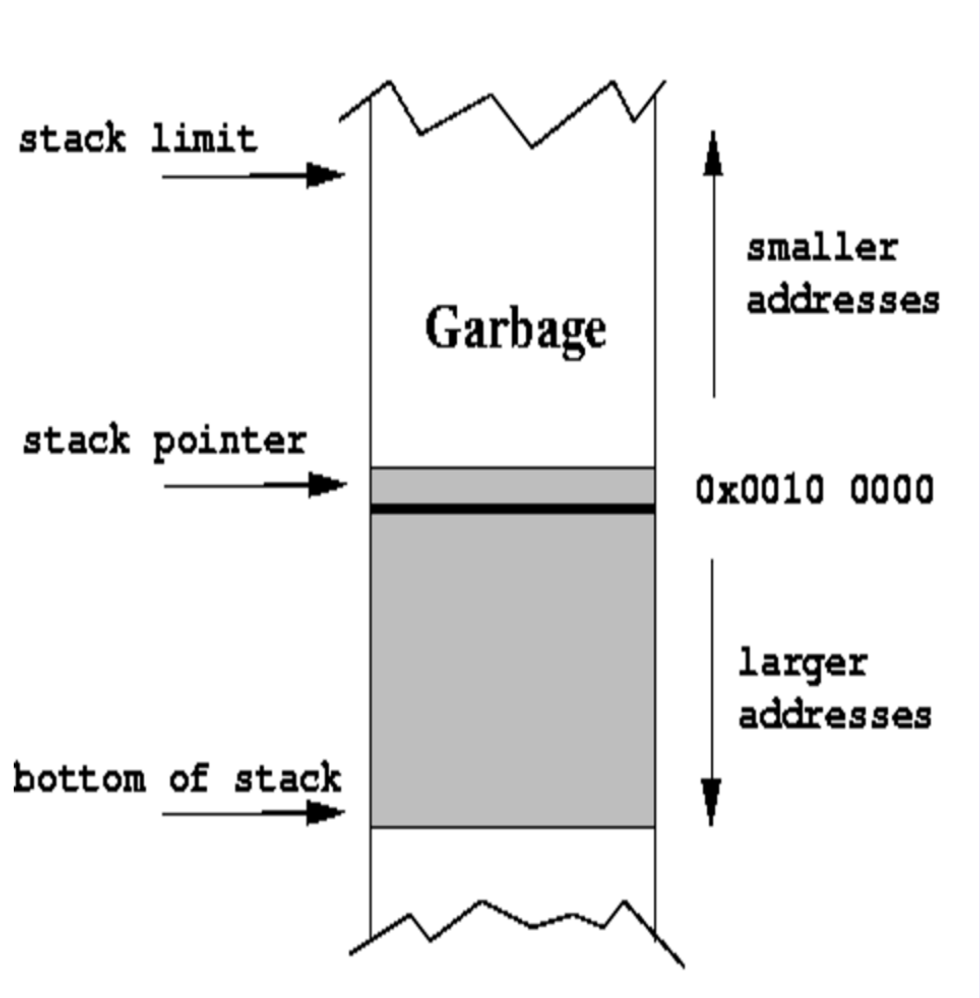
$sp

$s2

$s1

$s0

Bottom of stack



An Illustrative Example

```
…
…
int subTwo(int a, int b)
{
  int sub = a - b;
  return sub;
}


int doSomething(int x, int y)
{
  int a = subTwo(x, y);
  int b = subTwo(y, x);
  return a + b;
}
…
…
```

<u>subTwo doesn’t call anything</u>

What should I map **a** and **b** to?

$a0 and $a1

Can I map **sub** to **$t0**?

*Ok, b/c I don’t care about **$t****
(not the best tactic, tho…)

*Eventually, I have to have **sub** be **$v0***

<u>doSomething DOES call a function</u>

What should I map **x** and **y** to?

*Since we want to preserve them across the call to subTwo, we should map them to **$s0** and **$s1***

What should I map **a** and **b** to?

*“**a+b**” has to eventually be **$v0**. I should make at least **a** be a preserved reg (**$s2**). Since I get **b** back from a call and there’s <u>no other call after it</u>, I can likely get away with not using a preserved reg for **b**.*

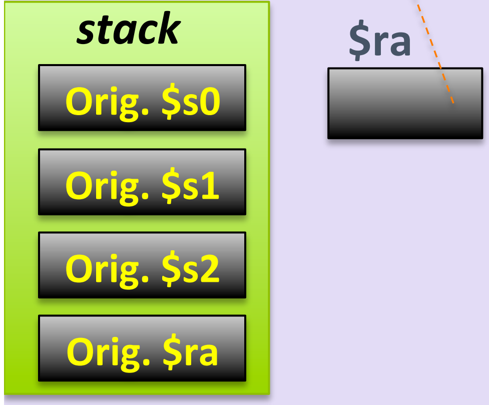
```
subTwo:
sub $v0, $a0, $a1
jr $ra

doSomething:
# preserve for the sake
# of whatever called
# doSomething
addiu $sp, $sp, -16
sw $s0, 0($sp)
sw $s1, 4($sp)
sw $s2, 8($sp)
sw $ra, 12($sp)

move $s0, $a0
move $s1, $a1

jal subTwo

move $s2, $v0
```

```
move $a0, $s1
move $a1, $s0

jal subTwo

add $v0, $v0, $s2

# pop back the preserved
# so that they're ready
# for whatever called
# doSomething
lw $s0, 0($sp)
lw $s1, 4($sp)
lw $s2, 8($sp)
lw $ra, 12($sp)
addiu $sp, $sp, 16

jr $ra
```

```
int subTwo(int a, int b)
{
  int sub = a - b;
  return sub;
}

int doSomething(int x, int y)
{
  int a = subTwo(x, y);
  int b = subTwo(y, x);
  return a + b; }
```

```
subTwo:
sub $v0, $a0, $a1
jr $ra

doSomething:
addiu $sp, $sp, -16
sw $s0, 0($sp)
sw $s1, 4($sp)
sw $s2, 8($sp)
sw $ra, 12($sp)

move $s0, $a0
move $s1, $a1

jal subTwo
move $s2, $v0
move $a0, $s1
move $a1, $s0

jal subTwo

add $v0, $v0, $s2

lw $s0, 0($sp)
lw $s1, 4($sp)
lw $s2, 8($sp)
lw $ra, 12($sp)
addiu $sp, $sp, 16

jr $ra
```

```
int subTwo(int a, int b)
{
  int sub = a - b;
  return sub;
}

int doSomething(int x, int y)
{
  int a = subTwo(x, y);
  int b = subTwo(y, x);
  …
  return a + b;
}
```

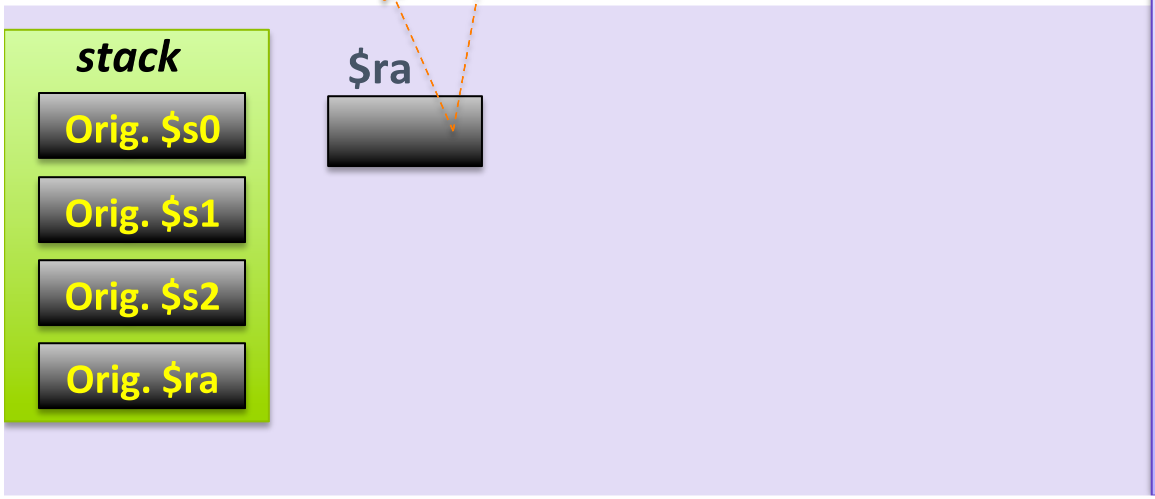


	$a0	$a1	
Arguments	int a	int b	
	$s0	$s1	$s2
Preserved	int a	int b	a – b
	$t0 - $t9		
Unpreserved			
	$v0		
Result Value	a – b		

```
subTwo:
sub $v0, $a0, $a1
jr $ra

doSomething:
addiu $sp, $sp, -16
sw $s0, 0($sp)
sw $s1, 4($sp)
sw $s2, 8($sp)
sw $ra, 12($sp)

move $s0, $a0
move $s1, $a1

jal subTwo
move $s2, $v0
```

```
move $a0, $s1
move $a1, $s0

jal subTwo

add $v0, $v0, $s2

lw $s0, 0($sp)
lw $s1, 4($sp)
lw $s2, 8($sp)
lw $ra, 12($sp)
addiu $sp, $sp, 16

jr $ra
```

```
int subTwo(int a, int b)
{
  int sub = a - b;
  return sub;
}

int doSomething(int x, int y)
{
  int a = subTwo(x, y);
  int b = subTwo(y, x);
  …
  return a + b;
}
```



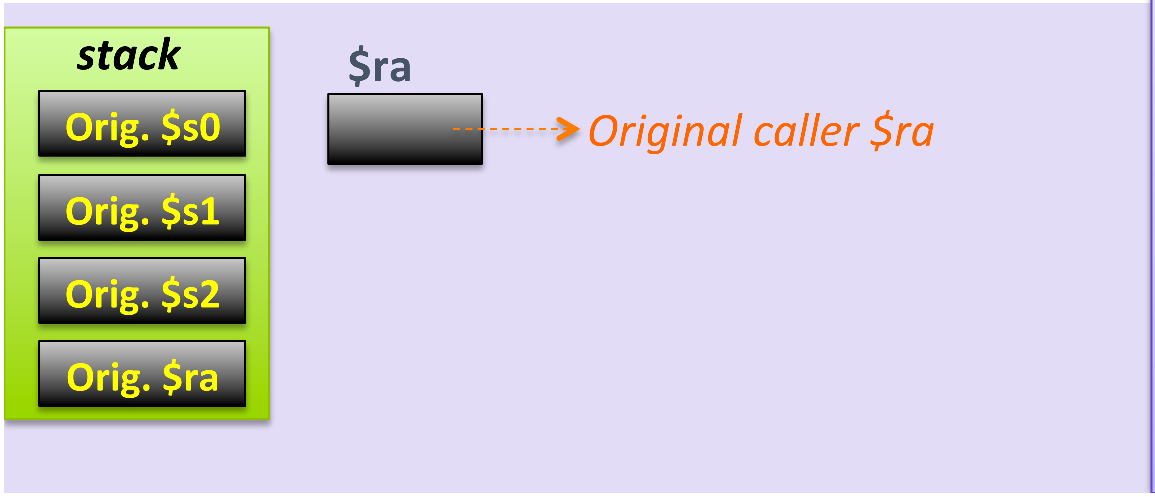
	$a0	$a1	
Arguments	int b	int a	
	$s0	$s1	$s2
Preserved	int a	int b	a – b
	$t0 - $t9		
Unpreserved			
	$v0		
Result Value	b – a → 0		

```
subTwo:
sub $v0, $a0, $a1
jr $ra

doSomething:
addiu $sp, $sp, -16
sw $s0, 0($sp)
sw $s1, 4($sp)
sw $s2, 8($sp)
sw $ra, 12($sp)

move $s0, $a0
move $s1, $a1

jal subTwo
move $s2, $v0
```

```
move $a0, $s1
move $a1, $s0

jal subTwo

add $v0, $v0, $s2
```

```
lw $s0, 0($sp)
lw $s1, 4($sp)
lw $s2, 8($sp)
lw $ra, 12($sp)
addiu $sp, $sp, 16

jr $ra
```

```
int subTwo(int a, int b)
{
  int sub = a - b;
  return sub;
}

int doSomething(int x, int y)
{
  int a = subTwo(x, y);
  int b = subTwo(y, x);
  …
  return a + b;
}
```



stack

Orig. $s0

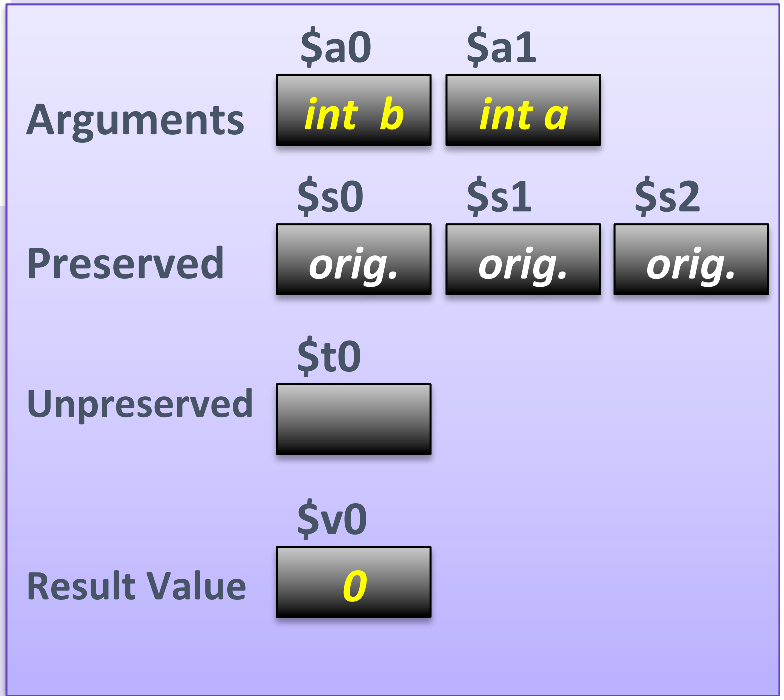
Orig. $s1

Orig. $s2

Orig. $ra

$ra

Original caller $ra



	$a0	$a1	
Arguments	*int b*	*int a*	
	$s0	$s1	$s2
Preserved	*orig.*	*orig.*	*orig.*
	$t0		
Unpreserved			
	$v0		
Result Value	*0*		

Lessons Learned

- We passed arguments into the functions using **`$a*`**

- We used **`$s*`** to work out calculations in registers ***that we wanted to preserve***, so we made sure to save them in the call stack
  - These var values DO need to live beyond a call
  - In the end, the original values were returned back

- We *could* use **`$t*`** to work out some calcs. in regs ***that we did not need to preserve***
  - These values DO NOT need to live beyond a function call

- We used **`$v*`** as regs. to return the value of the function

Another Example Using Recursion

Recursive Functions

- This same setup handles nested function calls and recursion
  - i.e. By saving `$ra` methodically on the stack

- Example: recursive_fibonacci.asm

recursive_fibonacci.asm

Recall the Fibonacci Series: 0, 1, 1, 2, 3, 5, 8, 13, etc…

fib(n) = fib(n – 1) + fib(n – 2)

In C/C++, we might write the recursive function as:

```
int fib(int n)
{
    if (n == 0)
        return (0);
    else
        if (n == 1)
            return (1);
        else
            return (fib(n-1) + fib(n-2));
}
```

Base cases

recursive_fibonacci.asm

- We'll need at least 3 registers to keep track of:
  - The (single) input to the call, i.e. var **n**
  - The output (or partial output) to the call
  - The value of **$ra** (since this is a recursive function)

- We'll use `$s*` registers b/c **we need to preserve these vars/regs. beyond the function call**

If we make `$s0` = **n** and `$s1` = **fib(n – 1)**

- Then we need to save `$s0`, `$s1` and `$ra` on the stack in the "fibonnaci" function
  - So that we do not corrupt/lose what's already in these regs

recursive_fibonacci.asm

- So, we start off in the **`main:`** portion
  - **n** is our argument into the function, so it’s in **$a0**

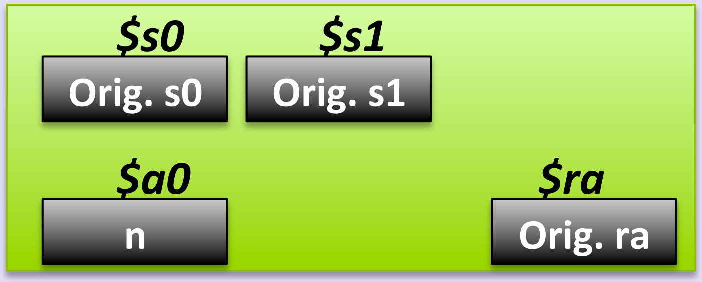
- We’ll put our number (example: 7) in $a0 and then call the function “fibonacci”
  - i.e.

    ```
    li $a0, 7
    jal fibonacci
    ```

recursive_fibonacci.asm

Inside the function "fibonacci"

- First: Check for the base cases
  - Is **n** ($a0) equal to 0 or 1?
  - Branch accordingly



$s0

Orig. s0

$s1

Orig. s1

$a0

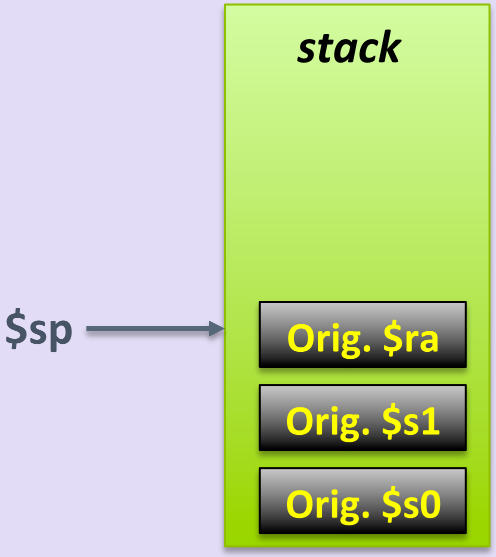
n

$ra

Orig. ra

- Next: Do the recursion --- but first…!

  We need to plan for 3 words in the stack
  - **$sp = $sp – 12**
  - **Push** 3 words in (i.e. 12 bytes)
  - The order by which you put them in does *not strictly* matter, *but* it makes more "organized" sense to ***push $s0, then $s1, then $ra***



stack

$sp

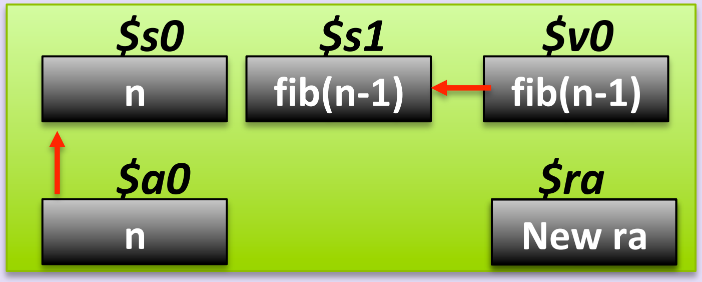
Orig. $ra

Orig. $s1

Orig. $s0

recursive_fibonacci.asm

- Next: calculate fib(n – 1)
  - Call recursively & copy output ($v0) in $s1
- Next: calculate fib(n – 2)

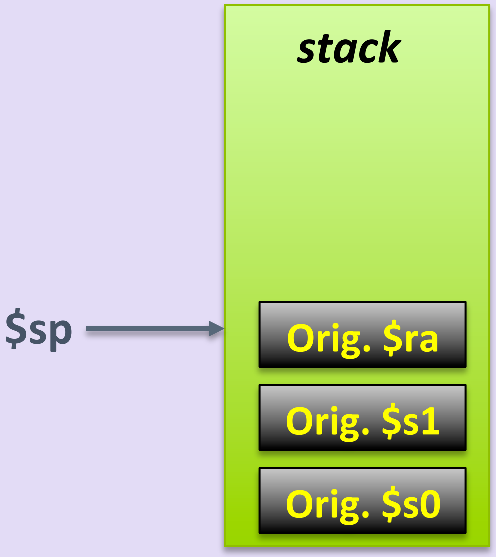


$s0 $s1 $v0

n fib(n-1) fib(n-1)

$a0 $ra

n New ra



stack

$sp

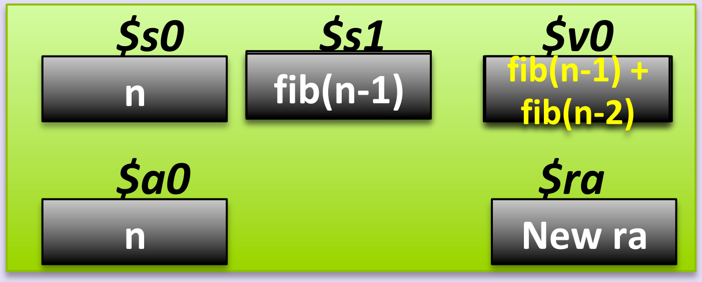
Orig. $ra

Orig. $s1

Orig. $s0

recursive_fibonacci.asm

- Next: calculate fib(n – 1)
  - Call recursively & copy output ($v0) in $s1
- Next: calculate fib(n – 2)
  - Call recursively & add $s1 to the output ($v0)



$s0

n

$s1

fib(n-1)

$v0

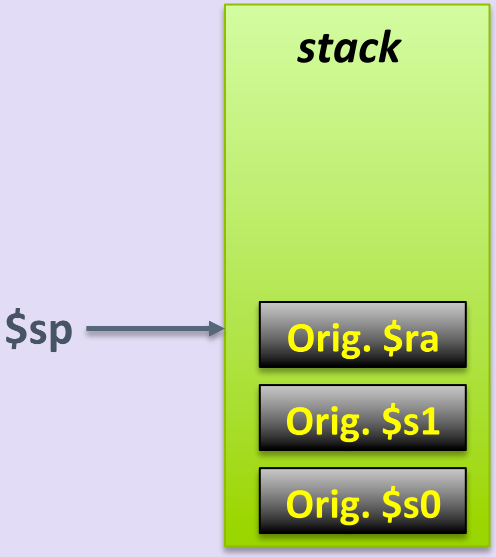
fib(n-1) + fib(n-2)

$a0

n

$ra

New ra



stack

$sp

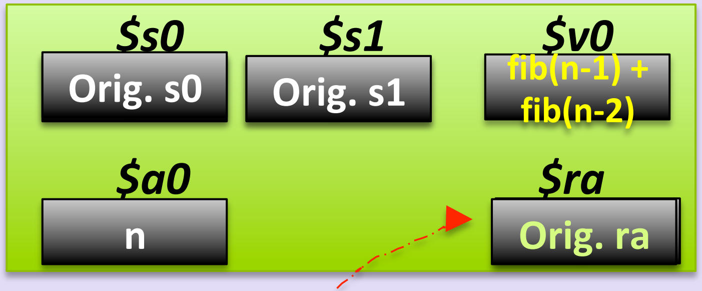
Orig. $ra

Orig. $s1

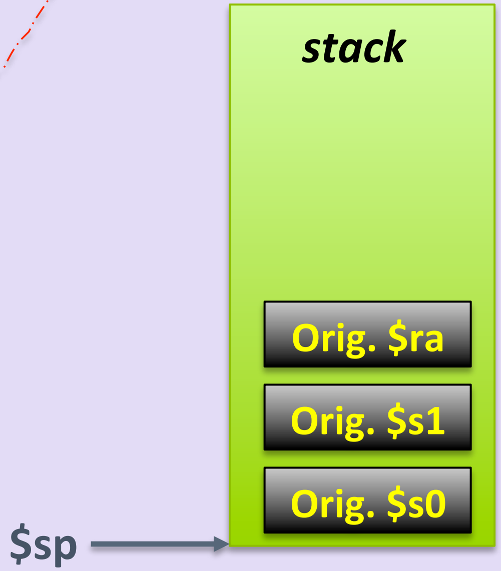
Orig. $s0

recursive_fibonacci.asm

- Next: calculate fib(n – 1)
  - Call recursively & copy output ($v0) in `$s1`
- Next: calculate fib(n – 2)
  - Call recursively & add $s1 to the output ($v0)
- Next: restore registers
  - Pop the 3 words back to `$s0`, `$s1`, and `$ra`
- Next: return to caller (i.e. main)
  - Issue a **`jr $ra`** instruction



- Note how when we leave the function and go back to the "callee" (main), we did not disturb what was in the registers previously
- And now we have our output where it should be, in **`$v0`**



A Closer Look at the Code

- Open **recursive_fibonacci.asm**

Tail Recursion

- Check out the demo file **tail_recursive_factorial.asm** at home
- What's special about the *tail recursive functions* (see example)?
  - **Where the recursive call is the very last thing in the function.**
  - With the right optimization, it can **use a constant stack space (no need to keep saving $ra over and over – it's more efficient)**

```
int TRFac(int n, int accum)
{
    if (n == 0)
        return accum;
    else
        return TRFac(n – 1, n * accum);
}
```

For example, if you said:
TRFac(4, 1)

Then the program would **return**:
TRFac(3, 4), then return
TRFac(2, 12), then return
TRFac(1, 24), then return
TRFac(0, 24), then, since **n = 0**,
It would return 24

Your To-Dos

- Again, MAKE SURE you've read the **MIPS Calling Convention PDF** from our class website
- Go over the **fibonnaci.asm** and **tail_recursive_factorial.asm** programs
- Next time: Intro to Digital Logic

</LECTURE>