Using the MIPS Calling Convention

Recursive Functions in Assembly

CS 64: Computer Organization and Design Logic
Lecture #10
Fall 2018

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Administrative

- Lab #5 this week – due on Friday
- Grades will be up on GauchoSpace today by noon!
  - If you want to review your exams, see your TAs:
    LAST NAMES **A thru Q** See **Bay-Yuan** (Th. 12:30 – 2:30 pm)
    LAST NAMES **R thru Z** See **Harmeet** (Th. 9:30 – 11:30 am)
- Mid-quarter evaluations for T.As
  - Links on the last slide and will put up on Piazza too
  - Optional to do, but very appreciated by us all!
- Remember: **NO CLASSES ON MONDAY!**
  - University holiday! Remember to thank a veteran!

Any Questions From Last Lecture?

5 Minute Pop Quiz!

Consider this C/C++ code:

```
void third() {}
void second() {third();}
void first() {second();}
int main() {first();}
```

And consider this supposedly equivalent MIPS code ➔ ➔

a) Are there any errors in it? (i.e. will it run?)

b) Does it follow the MIPS C.C.? **EXPLAIN YOUR ANSWER**

```
third:
   jr $ra
second:
   move $t0, $ra
   jal third
   jr $t0
first:
   move $t1, $ra
   jal second
   jr $t1
main:
   jal first
   li $v0, 10
   syscall
```

Lecture Outline

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

The MIPS Convention In Its Essence

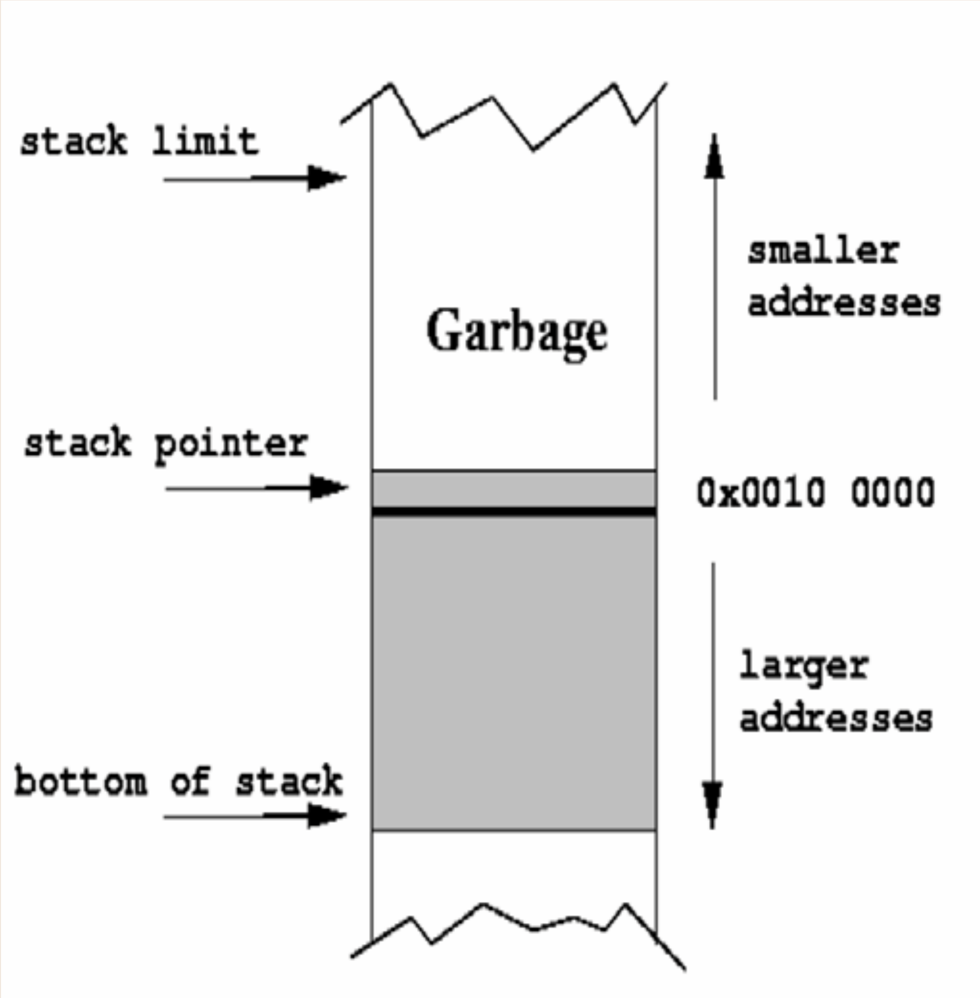
- Remember: Preserved vs Unpreserved Regs
- **Preserved**: **$s0 - $s7**, and **$sp, $ra**
- **Unpreserved**: **$t0 - $t9**, **$a0 - $a3**, and **$v0 - $v1**

- 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

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)*

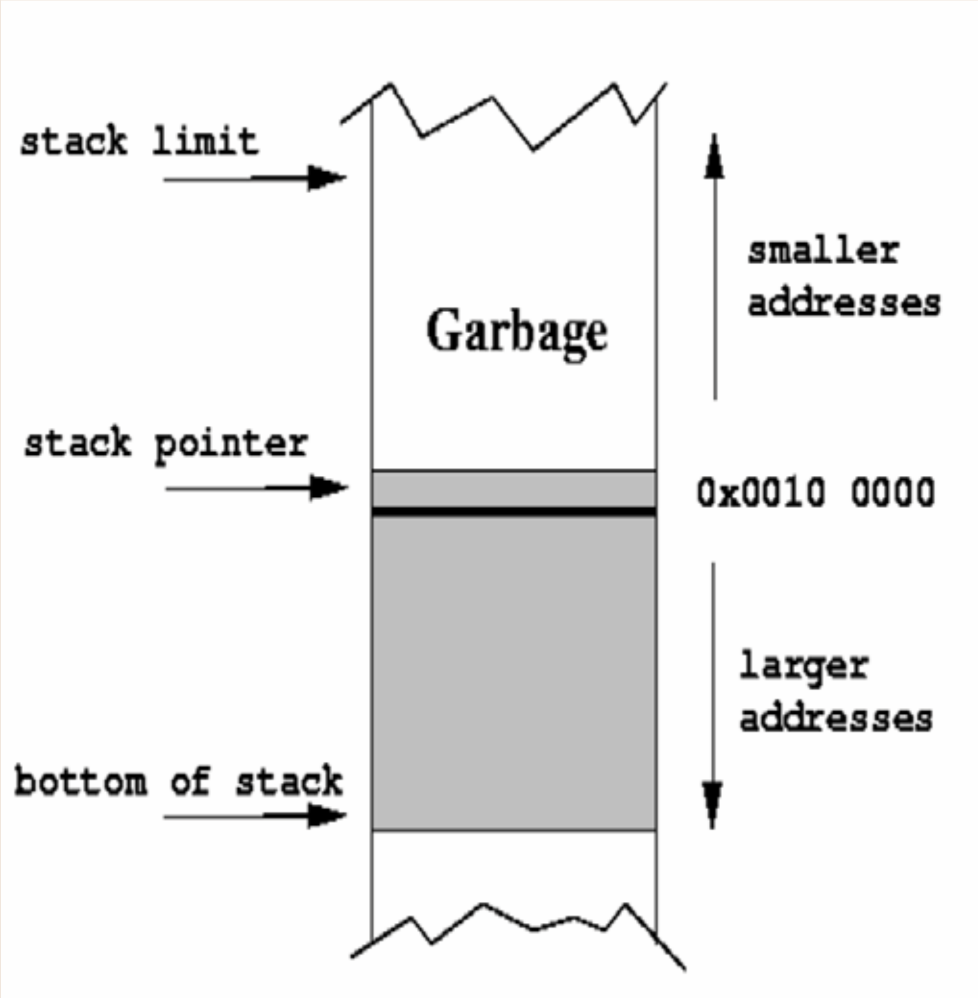


How the Stack Works

- *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

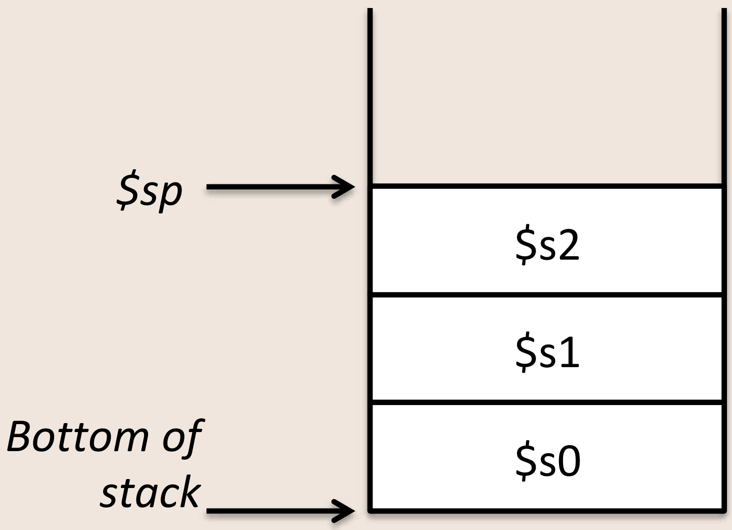


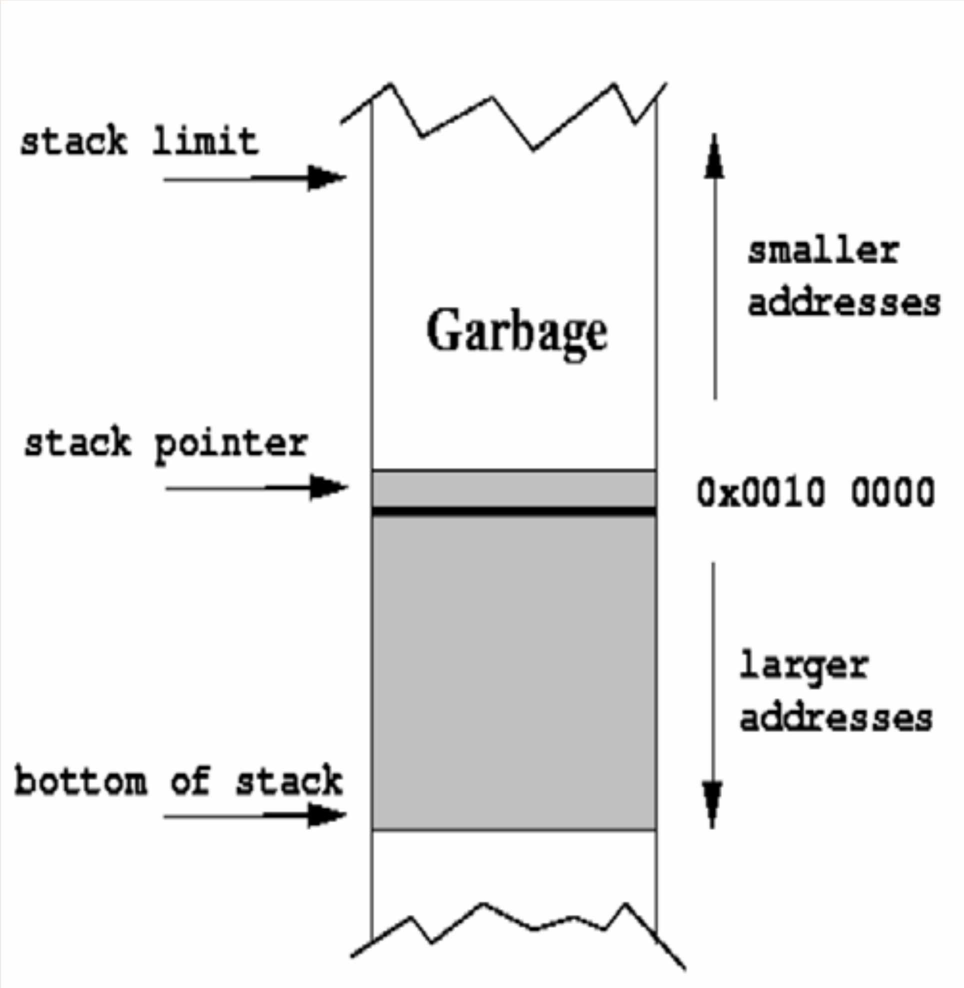
How the Stack Works

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)





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**.*

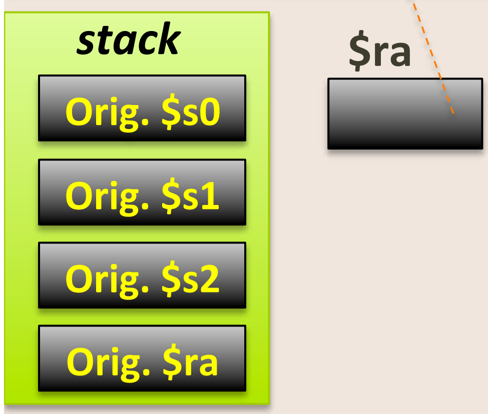
```
subTwo:
sub $v0, $a0, $a1
jr $ra

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
```

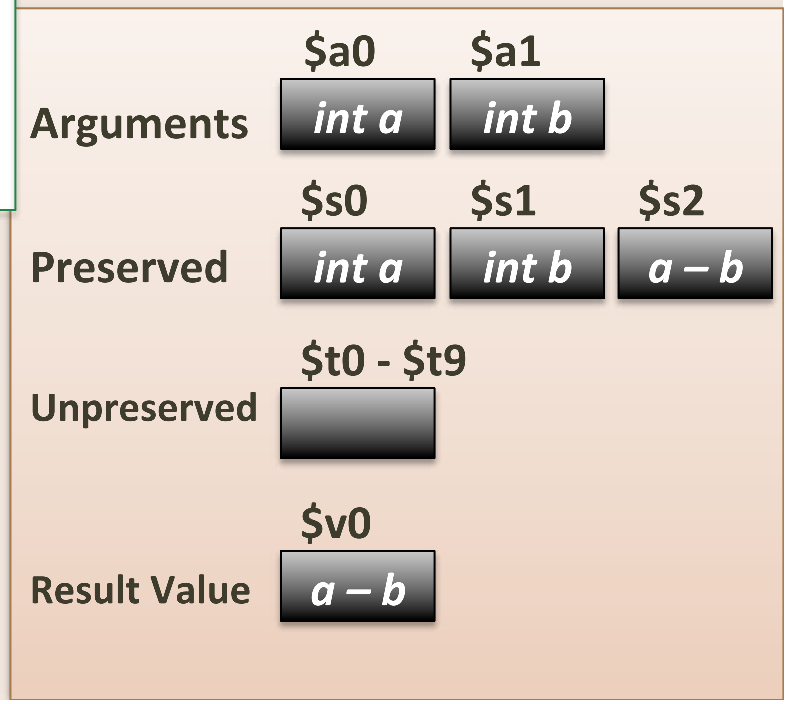
```
move $a0, $s1
move $a1, $s0

jal subTwo

add $v0, $v0, $s2

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

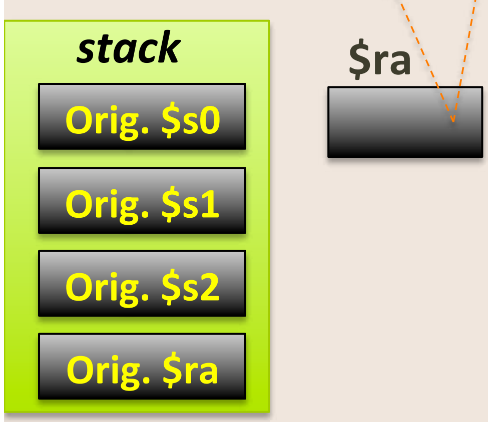


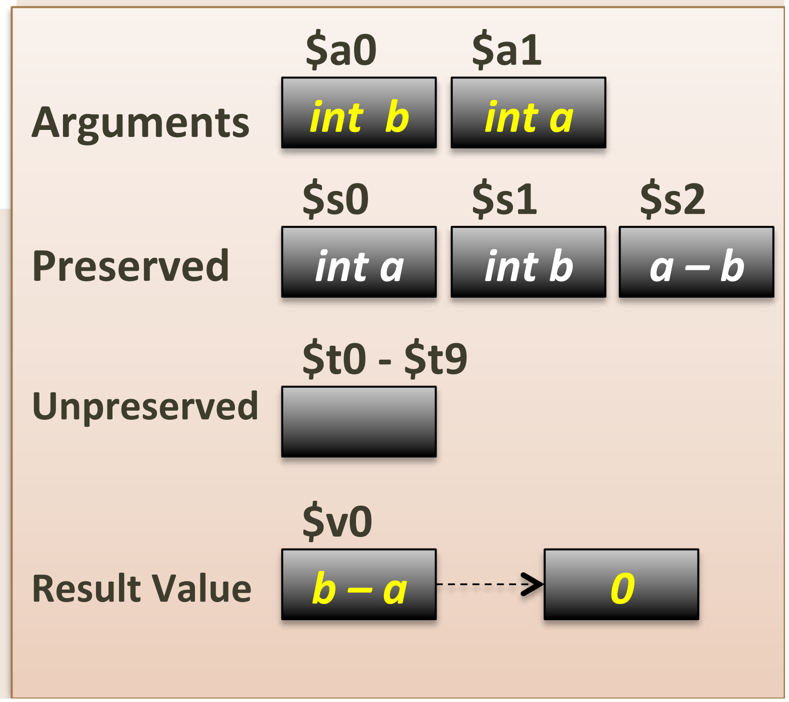


```
subTwo:
sub $v0, $a0, $a1
jr $ra

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

jr $ra
```

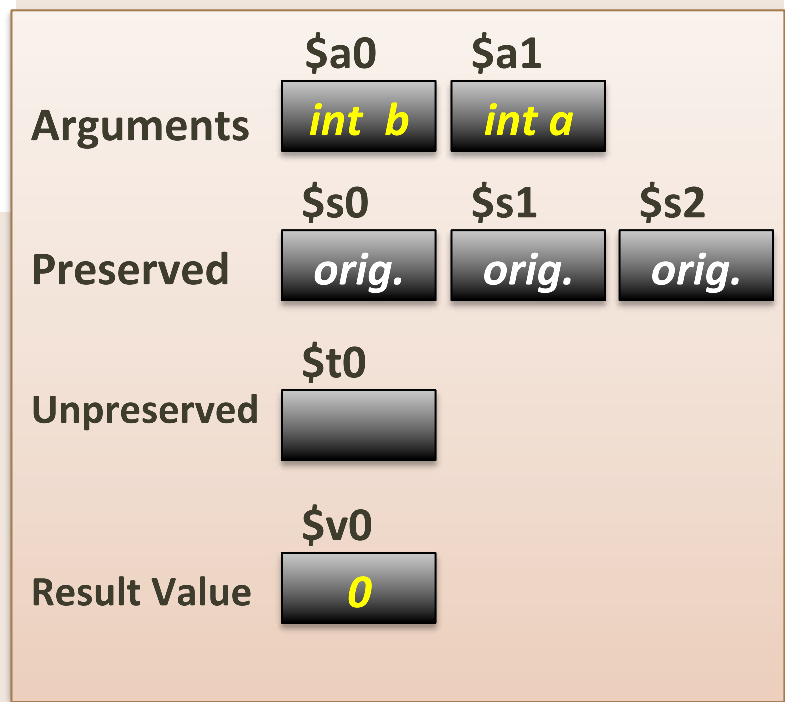
```
int subTwo(int a, int b)
{
  int sub = a - b;
  return sub;
}

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 $ra, 12($sp)
lw $s2, 8($sp)
lw $s1, 4($sp)
lw $s0, 0($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;
}
```



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 (the `if (n == 0)` and `if (n == 1)` branches)

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
```

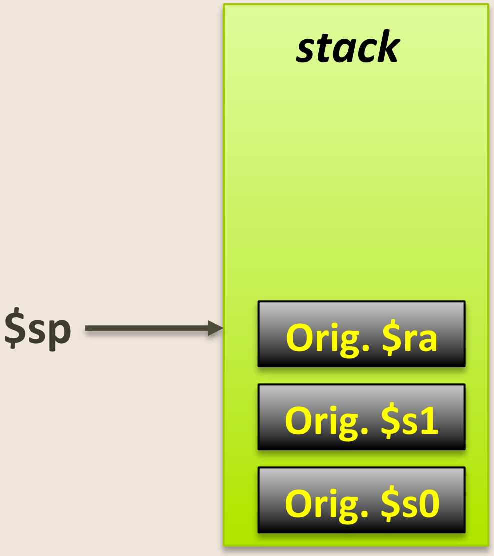
recursive_fibonacci.asm

Inside the function "fibonacci"

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

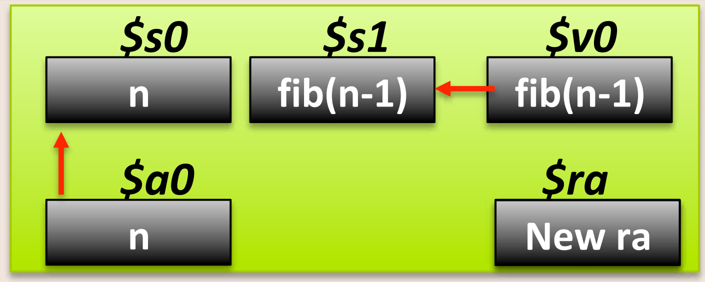
- Next: Do the recursion --- but first…!

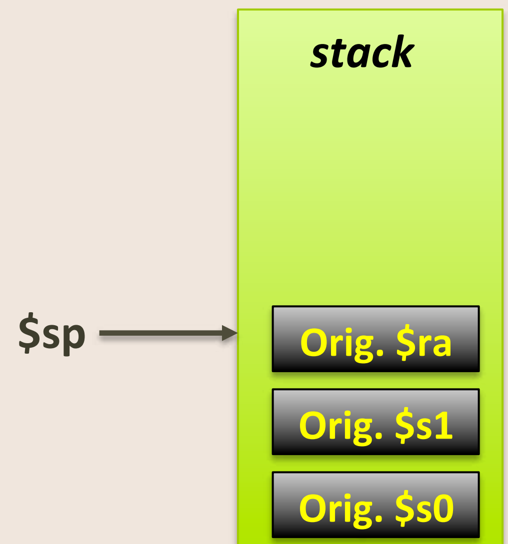
  We need to plan for 3 words in the stack
  - **$sp = $sp – 12**
  - **Push** 3 words in (i.e. 12 bytes)
  - The order by which you put them in does *not strictly* matter, ***but*** it makes more "organized" sense to ***push $s0, then $s1, then $ra***



recursive_fibonacci.asm

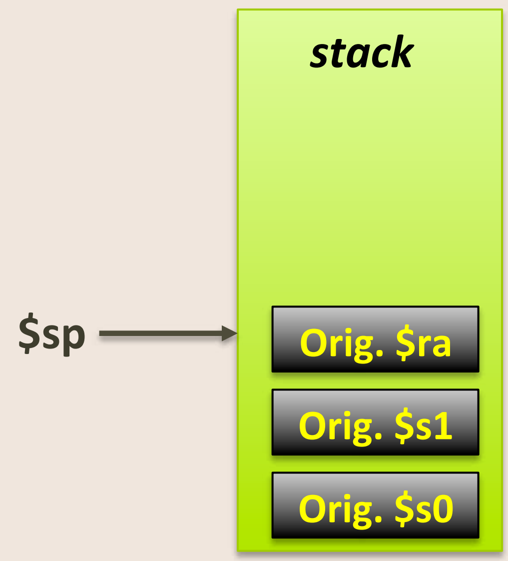
- Next: calculate fib(n – 1)
  - Call recursively & copy output ($v0) in $s1
- Next: calculate fib(n – 2)





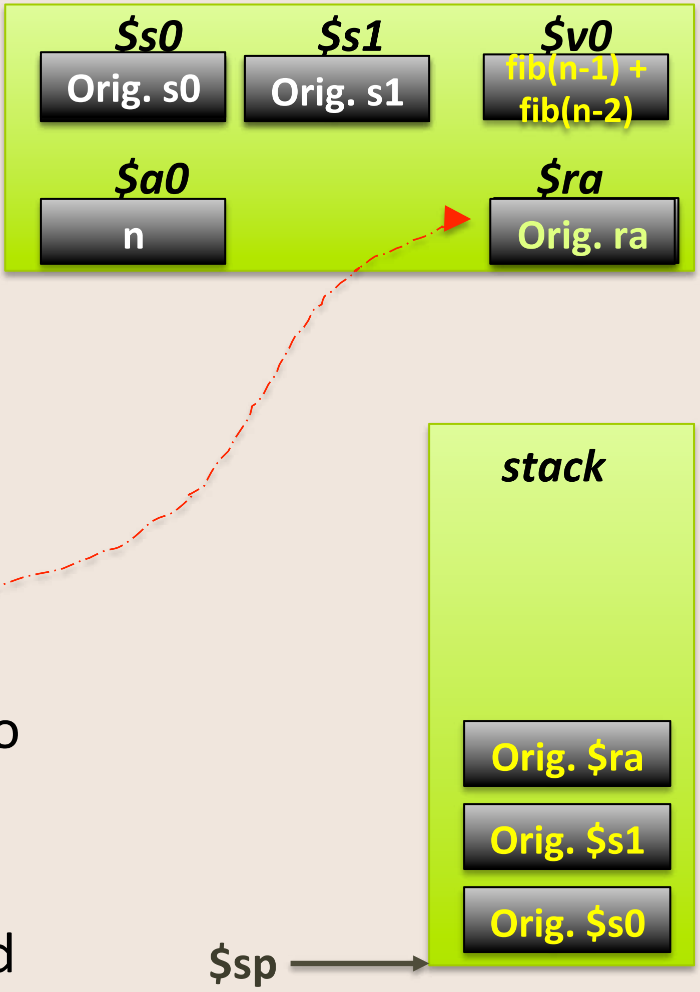
recursive_fibonacci.asm

- 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)



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 week: Intro to Digital Logic
  (on Wed., 'cuz we don't have class on Mon.!!!!)

</LECTURE>