

Recursive Procedure

- A recursive procedure is one which calls itself
- We can use the stack to implement recursive procedures

Recursive Example: Factorial

```
static int factorial( int n )
{
    if ( n <= 0 )    // base case
        return 1;
    else            // general case
        return ( n * factorial ( n - 1 ) );
}
```

Recursive Factorial in MIPS

```
# int fact(int n): return n <= 0 ? 1 : n * fact(n-1);
fact:
    addi $sp, $sp, -8          # space for two words
    sw $ra, 4($sp)             # save return address - push
    sw $a0, 0($sp)             # temporary variable to hold n - push
    li $v0, 1
    ble $a0, $zero, fact_return
    addi $a0, $a0, -1
    jal fact
    lw $a0, 0($sp)             # retrieve original n
    mul $v0, $v0, $a0          # n * fact(n - 1)

fact_return:
    lw $ra, 4($sp)             # restore $ra - pop
    addi $sp, $sp, 8           # restore $sp - pop
    jr $ra                     # back to caller
```

Recursive Simulation

Assume an input n=3, return address of main: 00400068
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$sp/\$fp → 7ffeffc	00000000

Recursive Simulation

Assume an input n=3, return address of main: 00400068
fact= 00400024, tmp1=00400044, fact_return= 0040004c

fact: **addi \$sp, \$sp, -8**

sw \$ra, 4(\$sp)

sw \$a0, 0(\$sp)

li \$v0, 1

ble \$a0, \$zero, fact_return

addi \$a0, \$a0, -1

jal fact

tmp1: lw \$a0, 0(\$sp)

mul \$v0, \$v0, \$a0

fact_return:

lw \$ra 4(\$sp)

addi \$sp, \$sp, 8

jr \$ra

Address	Stack
\$fp → 7fffeffc	00000000
\$sp → 7fffeff4	

Recursive Simulation

Assume an input n=3, return address of main: 00400068
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	?
\$sp → 7ffeff4	

Recursive Simulation

Assume an input n=3, return address of main: 00400068
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
\$sp → 7ffeff4	

Recursive Simulation

Assume an input $n=3$, $\text{fact}=00400024$,
 $\text{tmpl}=00400044$, $\text{fact_return}=0040004c$

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmpl: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
\$sp → 7fffeff4	?

Recursive Simulation

Assume an input n=3, fact= 00400024,
tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmpl: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
\$sp → 7fffeff4	00000003

Recursive Simulation

Assume an input n=3, fact= 00400024,
tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1      #($v0)=1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmpl: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp -> 7fffeffc	00000000
	00400068
\$sp -> 7fffeff4	00000003

Recursive Simulation

Assume an input n=3, return address of main: 00400068
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
\$sp → 7ffeff4	00000003

Recursive Simulation

n=2, fact= 00400024,
tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1    #($a0)=2
      jal fact
tmpl: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
\$sp → 7ffeff4	00000003

Recursive Simulation

n=2, (\$ra) =00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp -> 7fffeffc	00000000
	00400068
\$sp -> 7fffeff4	00000003

Recursive Simulation

n=2, (\$ra) =00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
\$sp → 7fffefec	

Recursive Simulation

n=2, (\$ra) =00400044
fact= 00400024, tml=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tml: lw $a0, 0($sp)
    mul $v0, $v0, $a0
fact_return:
    lw $ra 4($sp)
    addi $sp, $sp, 8
    jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	?
\$sp → 7fffefec	

Recursive Simulation

n=2, (\$ra) =00400044

fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7fffefec	

Recursive Simulation

n=2, (\$ra) =00400044
fact= 00400024, tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
templ: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7ffefec	?

Recursive Simulation

n=2, (\$ra) =00400044

fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7ffefec	00000002

Recursive Simulation

n=2, (\$ra) =00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7ffefec	00000002

Recursive Simulation

n=2, (\$ra) =00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7ffefec	00000002

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
templ: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7ffefec	00000002

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7ffefec	00000002

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp → 7ffefe4	

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp -> 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp -> 7ffefe4	?

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp -> 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp -> 7ffefe4	00400044

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp:  lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp → 7ffefe4	00400044
	?

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp → 7fffe4	00400044
	00000001

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
templ: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp → 7fffefe4	00400044
	00000001

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp → 7ffefe4	00400044
	00000001

Recursive Simulation

n=0, (\$ra)=00400044
fact= 00400024, tml=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tml: lw $a0, 0($sp)
    mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp → 7ffefe4	00400044
	00000001

Recursive Simulation

n=0, (\$ra)=00400044
fact= 00400024, tmp=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp: lw $a0, 0($sp)
    mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp → 7ffefe4	00400044
	00000001

Recursive Simulation

n=0, (\$ra)=00400044

fact= 00400024, tmp1=00400044, fact_return= 0040004c

fact: **addi \$sp, \$sp, -8**

sw \$ra, 4(\$sp)

sw \$a0, 0(\$sp)

li \$v0, 1

ble \$a0, \$zero, fact_return

addi \$a0, \$a0, -1

jal fact

tmp1: lw \$a0, 0(\$sp)

mul \$v0, \$v0, \$a0

fact_return:

lw \$ra 4(\$sp)

addi \$sp, \$sp, 8

jr \$ra

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
	00000001
\$sp → 7ffefdc	

Recursive Simulation

n=0, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
\$sp → 7ffefdc	00000001
	?

Recursive Simulation

n=0, (\$ra)=00400044

fact= 00400024, tmp1=00400044, fact_return= 0040004c

fact: addi \$sp, \$sp, -8

sw \$ra, 4(\$sp)

sw \$a0, 0(\$sp)

li \$v0, 1

ble \$a0, \$zero, fact_return

addi \$a0, \$a0, -1

jal fact

tmp1: lw \$a0, 0(\$sp)

mul \$v0, \$v0, \$a0

fact_return:

lw \$ra 4(\$sp)

addi \$sp, \$sp, 8

jr \$ra

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
	00000001
	00400044
\$sp → 7ffefdc	

Recursive Simulation

n=0, (\$ra)=00400044
fact= 00400024, tmp=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp:  lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
	00000001
	00400044
\$sp → 7ffefdc	?

Recursive Simulation

n=0, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
	00000001
\$sp → 7ffefdc	00400044
	00000000

Recursive Simulation

n=0, (\$ra)=00400044
fact= 00400024, tml=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tml: lw $a0, 0($sp)
    mul $v0, $v0, $a0
fact_return:
    lw $ra 4($sp)
    addi $sp, $sp, 8
    jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
\$sp → 7ffefdc	00000001
	00400044
	00000000

Recursive Simulation

n=0, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
	00000001
\$sp → 7ffefdc	00400044
	00000000

Recursive Simulation

n=0, (\$ra)=00400044

fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
	00000001
\$sp → 7ffefdc	00400044
	00000000

Recursive Simulation

n=0, (\$ra)=00400044
fact= 00400024, tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
templ: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp →7fffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp →7fffefe4	00400044
	00000001
	00400044
7fffefdc	00000000

Recursive Simulation

n=0, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
\$sp → 7fffe4	00000001
	00400044
	00000000
7ffefdc	

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
\$sp → 7fffefe4	00000001
	00400044
7fffefdc	00000000

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
templ: lw $a0, 0($sp)
      mul $v0, $v0, $a0  #($v0)=1
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
	00000003
	00400044
	00000002
	00400044
\$sp → 7fffefe4	00000001
	00400044
7fffefdc	00000000

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0  #($v0)=1
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
	00000003
	00400044
	00000002
\$sp → 7fffe4	00400044
	00000001
	00400044
7ffefdc	00000000

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0  #($v0)=1
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp →7fffeffc	00000000
	00400068
	00000003
	00400044
\$sp →7fffefec	00000002
	00400044
7fffe4	00000001
	00400044
7ffefdc	00000000

Recursive Simulation

n=1, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)
      mul $v0, $v0, $a0  #($v0)=1
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7fffefec	00000002
	00400044
7fffefe4	00000001
	00400044
7fffefdc	00000000

Recursive Simulation

n=2, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)  #($a0)=2
      mul $v0, $v0, $a0  #($v0)=1
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7fffefec	00000002
	00400044
7fffe4	00000001
	00400044
7ffefdc	00000000

Recursive Simulation

n=2, (\$ra)=00400044
fact= 00400024, tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmpl: lw $a0, 0($sp)    #($a0)=2
      mul $v0, $v0, $a0 #($v0)=2
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7fffefec	00000002
	00400044
7fffefe4	00000001
	00400044
7fffefdc	00000000

Recursive Simulation

n=2, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)    #($a0)=2
      mul $v0, $v0, $a0  #($v0)=2
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7fffeffc	00000000
	00400068
	00000003
	00400044
\$sp → 7fffefec	00000002
	00400044
7fffefe4	00000001
	00400044
7fffefdc	00000000

Recursive Simulation

n=2, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)    #($a0)=2
      mul $v0, $v0, $a0  #($v0)=2
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
\$sp → 7ffeff4	00000003
	00400044
7ffefec	00000002
	00400044
7ffefe4	00000001
	00400044
7ffefdc	00000000

Recursive Simulation

n=2, (\$ra)=00400044
fact= 00400024, tml=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tml:  lw $a0, 0($sp)    #($a0)=2
      mul $v0, $v0, $a0 #($v0)=2
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
\$sp → 7ffeff4	00000003
	00400044
7ffefec	00000002
	00400044
7ffefe4	00000001
	00400044
7ffefdc	00000000

Recursive Simulation

n=3, (\$ra)=00400044
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)  #($a0)=3
      mul $v0, $v0, $a0  #($v0)=2
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
\$sp → 7ffeff4	00000003
	00400044
7ffefec	00000002
	00400044
7ffefe4	00000001
	00400044
7ffefdc	00000000

Recursive Simulation

n=3, (\$ra)=00400044

fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)    #($a0)=3
      mul $v0, $v0, $a0  #($v0)=6
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
\$sp → 7ffeff4	00000003
	00400044
7ffefec	00000002
	00400044
7ffefe4	00000001
	00400044
7ffefdc	00000000

Recursive Simulation

n=3, (\$ra)=00400068 (return address of main)
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)    #($a0)=3
      mul $v0, $v0, $a0 #($v0)=6
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$fp → 7ffeffc	00000000
	00400068
\$sp → 7ffeff4	00000003
	00400044
7ffefec	00000002
	00400044
7ffefe4	00000001
	00400044
7ffefdc	00000000

Recursive Simulation

n=3, (\$ra)=00400068 (return address of main)
fact= 00400024, tmpl=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmpl: lw $a0, 0($sp)    #($a0)=3
      mul $v0, $v0, $a0 #($v0)=6
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra
```

Address	Stack
\$sp/\$fp → 7fffeffc	00000000
	00400068
7fffeff4	00000003
	00400044
7fffefec	00000002
	00400044
7fffe4e4	00000001
	00400044
7fffefdc	00000000

Recursive Simulation

n=3, (\$ra)=00400068 (return address of main)
fact= 00400024, tmp1=00400044, fact_return= 0040004c

```
fact: addi $sp, $sp, -8
      sw $ra, 4($sp)
      sw $a0, 0($sp)
      li $v0, 1
      ble $a0, $zero, fact_return
      addi $a0, $a0, -1
      jal fact
tmp1: lw $a0, 0($sp)    #($a0)=3
      mul $v0, $v0, $a0 #($v0)=6
fact_return:
      lw $ra 4($sp)
      addi $sp, $sp, 8
      jr $ra           #return to main
```

Address	Stack
\$sp/\$fp →7fffeffc	00000000
	00400068
7fffeff4	00000003
	00400044
7fffefec	00000002
	00400044
7fffe4e4	00000001
	00400044
7fffefdc	00000000