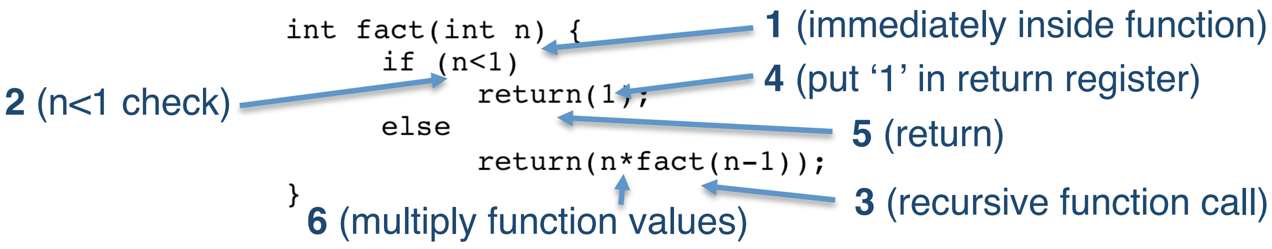
Part H: Recursive Function Calls



```
int fact(int n) {
    if (n<1)
        return(1);
    else
        return(n*fact(n-1));
}
```

1 (immediately inside function)
2 (n<1 check)
4 (put ‘1’ in return register)
5 (return)
3 (recursive function call)
6 (multiply function values)

Part A:

Let’s consider how we might use the stack to support these nested calls. We’ll also make use of the frame pointer ($fp).

Code Section #	Address	Label	MIPS Instruction	Comments
1	0	Fact:	subi $sp, $sp, 12	Make room for 3 pieces of data on the stack; $fp, $sp, and 1 local argument
	4		sw 8($sp), $ra	If $sp = 88, M(88 + 8) ← value of $ra
	8		sw 4($sp), $fp	If $sp = 88, M(88 + 4) ← value of $fp
	12		subi $fp, $fp, 12	Update the frame pointer
2	16		bgtz $a0, L2	If N > 0 (i.e. not < 1) we’re not done → we assume N is in $a0
4	20		addi $v0, $0, 1	We eventually finish and want to return 1, therefore put 1 in return register
	24		j L1	Jump to return code
3	28	L2:	sw $a0, 0($fp)	Save argument N to stack (we’ll need it when we return)
	32		subi $a0, $a0, 1	Decrement N (N = N – 1), put result in $a0
	36		jal Fact	Call Factorial() again
6	40		lw $t0, 0($f0)	Load N (saved at *** to stack)
	44		mult $v0, $v0, $t0	Store result in $v0
5	48	L1:	lw $ra, 8($sp)	Restore return address
	52		lw $fp, 4($sp)	Restore frame pointer
	56		addi $sp, $sp, 12	Pop stack
	60		jr $ra	Return from factorial

4 N > 1?

5 If so, store old value of N (data that needs to be saved), ref $fp

8a More of the same

9 $ra is in factorial

10a More of the same

Code Trace:

1st Call to Factorial

Addr	What Happens
0	$sp = $sp-12; $sp ← 100
4	M(100+8) = M(108) ← $ra
8	M(100+4) = M(104) ← $fp
12	$fp = $fp-12; $fp ← 112
16	2 is greater than 0
28	M($fp / 112) ← N (store #)
32	N = N-1 (new arg = 1)
36	jal Fact ($ra = 40_{10})

2nd Call to Factorial

Addr	What Happens
0	$sp = $sp-12; $sp ← 88
4	M(96) ← $ra ($ra=40)
8	M(92) ← $fp ($fp =112)
12	$fp = $fp-12; $fp ← 100
16	1 is greater than 0
28	M($fp / 100) ← N (store #)
32	N = N-1 (new arg = 0)
36	jal Fact ($ra = 40_{10})

3rd Call to Factorial

Addr	What Happens
0	$sp = $sp-12; $sp ← 76
4	M(84) ← $ra ($ra=40)
8	M(80) ← $fp ($fp =100)
12	$fp = $fp-12; $fp ← 88
16	0 is NOT greater than 0
	(start to return)

10c Now meet exit criteria

6, 7 Calculate number to pass to function, call factorial again

12 Restore saved variable, calculate value to return: $v0 from old call, stored N; calculated value becomes $v0

Return from 3rd Call

Addr	What Happens
20	addi $v0, $0, 1 (return 1)
24	j L1
48	$ra ← M($sp+8) ← M(84) $ra ← 40
52	$fp ← M($sp+4) ← M(80) $fp ← 100
56	$sp = 76+12; $sp ← 88 (pop stack)
60	jr $ra implies that PC ← 40

Return from 2nd Call

Addr	What Happens
40	lw $t0, 0($fp); $t0 ← M(100); $t0 ← 1
44	$v0 ← 1x1 $v0 = return address reg.
48	$ra ← M($sp+8) ← M(96) $ra ← 40
52	$fp ← M($sp+4) ← M(92) $fp ← 112
56	$sp ← 88 + 12 = 100
60	jr $ra makes: PC ← 40

Return form 1st Call

Addr	What Happens
40	lw $t0, 0($fp); $t0 ← M(112); $t0 ← 2
44	$v0 ← 1x2 $v0 ← $v0 x $t0
48	$ra ← M($sp+8) ← M(108) $ra ← factorial caller RA
52	$fp ← M($sp+4) ← M(104) $fp ← factorial caller FP
56	$sp ← 100 + 12 = 112
60	jr $ra (PC + 4 of fact caller)

10d Undo stack pushes, “restore” $ra, $fp

11 Go back to jal + 4

13a Return as before

14a Calculate next value to return

Memory Contents: (Assume main() calls function which calls factorial.)

Memory Address	Before 1st Fact Call	During 1st Fact Call	During 2nd Fact Call	During 3rd Fact Call	Return from 3rd	Return from 2nd	Return from 1st
76				Current $sp			
80				Saved $fp from prior call (100)			
84				Saved $ra of fact (40)			
88			Current $sp	Current $fp N never stored	$sp 3rd fact call out		
92			Saved $fp from prior call (112)				
96			Saved $ra of fact (40)				
100		Current $sp	Current $fp N = 1			$sp 2nd fact call out	
104		Saved $fp of function calling fact (124)					
108		Saved $ra of function calling fact					
112	Current $sp	Current $fp N = 2					$sp 1st fact call out
116	Saved $fp of main						
120	Saved $ra of main						
124	Current $fp						

10b More of the same, $ra = 40

10e Pop Stack

1 make room for $sp, $fp, N

13b Pop Stack

2 save $ra, $fp (prep for new call)

8a More of the same, $ra = 40

3 update $fp to define start of call frame

Callee saving

14b Pop Stack; restore address of function that called factorial

0 Main() calls function which calls factorial