

ELEC2041

Microprocessors and Interfacing

Lectures 15 : Functions in C/ Assembly - I

<http://webct.edtec.unsw.edu.au/>

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Saeid Nooshabadi

saeid@unsw.edu.au

Overview

- C functions
- Bookkeeping for function call/return
- Instruction support for functions
- Nested function calls
- C memory allocation: static, heap, stack
- Conclusion

Review

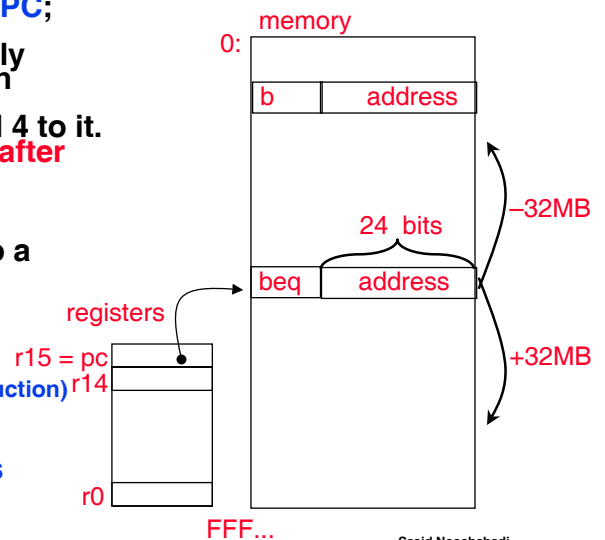
- HLL decisions (if, case) and loops (while, for) use same assembly instructions

- Flag Setting Instructions: `cmp`, `cmn`, `tst`, `teq` in ARM
- Data Processing Instructions with Flag setting Feature: `adds`, `subs`, `ands`, in ARM
- Conditional branches: `beq`, `bne`, `bgt`, `blt`, etc in ARM
- Conditional Instructions: `addeq`, `ldreq`, etc in ARM
- Unconditional branches: `b`, `bal`, and `mv pc, Rn` in ARM
- Switch/Case: chained if-else or jump table + `ldr pc, []`

- `ldr pc, []` is VERY POWERFUL!

Review: Branches: PC-relative addressing

- Recall register `r15` in the machine also called `PC`;
- points to the currently executing instruction
- Most instruction add 4 to it. (pc increments by 4 after execution of most instructions)
- Branch changes it to a specific value
- Branch adds to it
 - 24-bit signed value (contained in the instruction)
 - Shifted left by 2 bits
- Labels => addresses



C functions

```
main(void) {
    int i,j,k,m;

    i = mult(j,k); ... ;
    m = mult(i,i); ... ;
}

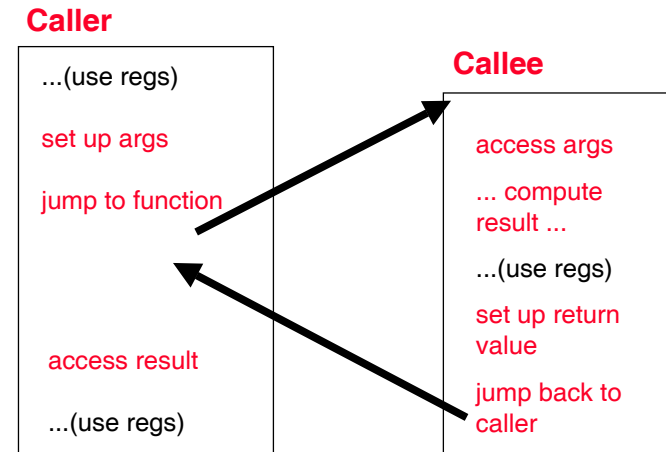
int mult (int mcand, int mlier)
{
    int product = 0;
    while (mlier > 0) {
        product = product + mcand;
        mlier = mlier -1;
    }
    return product;
}
```

What information must compiler/program keep track of?

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Basics of Function Call



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Function Call Bookkeeping

- Procedure address **Registers for functions**
- Return address → lr = r14
- Arguments → a1, a2, a3, a4
- Return value → a1
- Local variables → v1, v2, v3, v4, v5, v6, v8
- Registers (conflicts)

=>ARM Procedure Call Standards (APCS) conventions for use of registers simplify bookkeeping

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APCS Register Convention: Summary

register name	software name	use and linkage
r0 – r3	a1 – a4	first 4 integer args
		scratch registers
		integer function results
r4 – r11	v1- v7	local variables
r9	sb	static variable base
r10	sl	stack limit
r11	fp/v8	frame pointer/local variable
r12	ip	intra procedure-call scratch pointer
r13	sp	stack pointer
r14	lr	return address
r15	pc	program counter

Red are SW conventions for compilation, blue are HW

ARM Procedure Call Standard (APCS)

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Instruction Support for Function Call?

```
C ... sum(a,b);... /* a,b:v1,v2 */
}
int sum(int x, int y) {
    return x+y;
}
```

```
A address
1000 mov a1,v1 ; x = a
R 1004 mov a2,v2 ; y = b
M 1008 mov lr,#1016 ; lr = 1016
1012 b sum ; jump to sum
1016 ...
```

```
2000 sum: add a1,a1,a2
2004 mov pc, lr ; b 1016
```

Why `mov pc, lr` vs. `b 1016` to return?

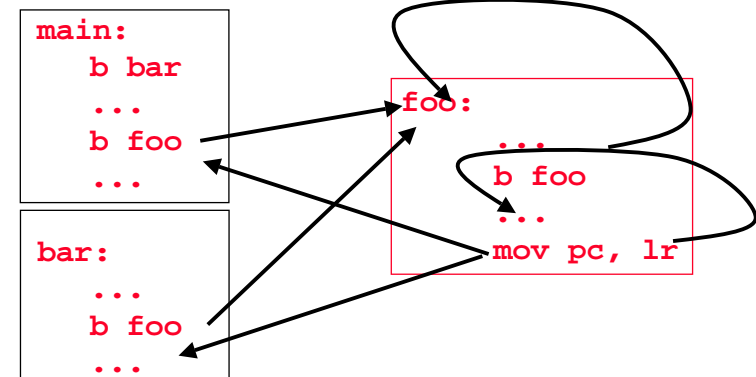
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`b` vs `mov pc, lr` : why jump register?

Consider a function `foo` that is called from several different places in your program

- each call is performed by a `b` instruction
 - `b foo`
- but the return jump goes to many places



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A Level of Indirection

◦ Solves many problems in CS!

◦ How do you make a jump instruction behave differently each time it is executed?

- indirection
 - `mov pc, lr` returns control to last caller
 - recorded in a registers

◦ How do you make an instruction fetch a different element of an array each time though a loop?

- indirection
- update index address register of `ldr`, and `str`

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Accessing array elements => indirection

```
int sumarray(int arr[]) {
    int i, sum;

    for(i=0;i<100;i=i+1)
        sum = sum + arr[i];
}
```

```
mov v1, #0 ; clear v0
add a2,a1,#400 ; beyond end of arr[]
Loop: cmp a1,a2
bge Exit
ldr a3,[a1], #4 ; a3=arr[i], a1++
add v1,v1,a3 ; v1= v1+ arr[i]
b Loop
Exit: mov lr, pc
```

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Instruction Support for Functions?

- Single instruction to branch and save return address: branch and link (**bl**):
- Before:

```
1008 mov lr, #1016 ;lr = 1016
1012 b sum ;goto sum
```
- After:

```
1012 bl sum ; lr = 1016,goto sum
```
- Why **bl**? Make the common case fast
 - and elegance

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Nested Procedures (#1/2)

```
...sumSquare(a,b)...
```

```
int sumSquare(int x, int y) {
    return mult(x,x)+ y;
}
```

- Need to save **sumSquare return address** saved in **lr** by **bl sumSquare** instruction, before call to **mult**
 - Otherwise **bl mult** overwrites **lr**
- One word per procedure in memory ?
 - e.g., `str lr, [sp,sumSquareRA] ; sp = r13`
- Recursive procedures could overwrite saved area => **need safe area per function invocation => stack**

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Nested Procedures (#2/2)

- In general, may need to save some other info in addition to **lr**.
- When a C program is run, there are 3 important memory areas allocated:
 - **Static:** Variables declared once per program, cease to exist only after execution completes
 - **Heap:** Variables declared dynamically (such as counters in `for` loops, or by function `malloc()`)
 - **Stack:** Space to be used by procedure during execution; this is where we can save register values

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“What’s This Stuff Good For?”



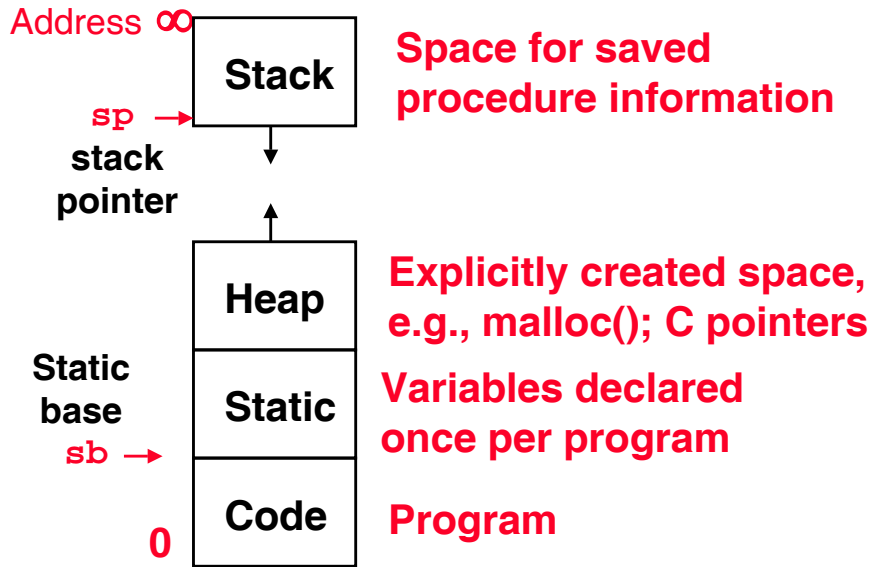
Breathing Observation Bubble: BOB pipes air from a tank under the handlebars into an acrylic dome, replacing a diver's face mask and breathing apparatus. Wireless technology lets riders talk to other BOBsters darting through the water nearby, as well as to armchair divers above in a boat or back on shore. Saving energy from not having to kick, divers can stay submerged almost an hour with the BOB. Like most modern scuba gear, the BOB features a computer that tells riders when to come up and calculates decompression times for a safe return to the surface. *One Digital Day*, 1998
www.intel.com/onedigitalday



What do applications (“apps”) like these mean for reliability requirements of our technology?

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C memory allocation seen by the Program



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Stack Operations

° PUSH v1

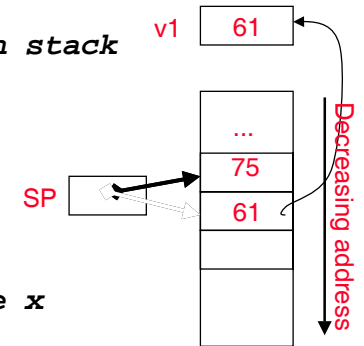
```
sub sp, sp, #4 ; space on stack
```

```
str v1, [sp, #0] ; save x
```

° POP v1

```
ldr v1, [sp, #0] ; restore x
```

```
add sp, sp, #4 ; => stack space
```



What does `sp` point to?

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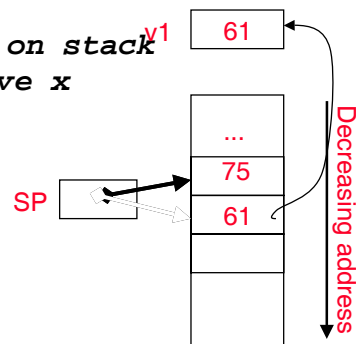
Stack Operations (Better Way)

° PUSH v1

```
str v1, [sp, #-4]! ; space on stack
; and save x
```

° POP v1

```
ldr v1, [sp], #4 ; restore x
; and reclaim stack space
```

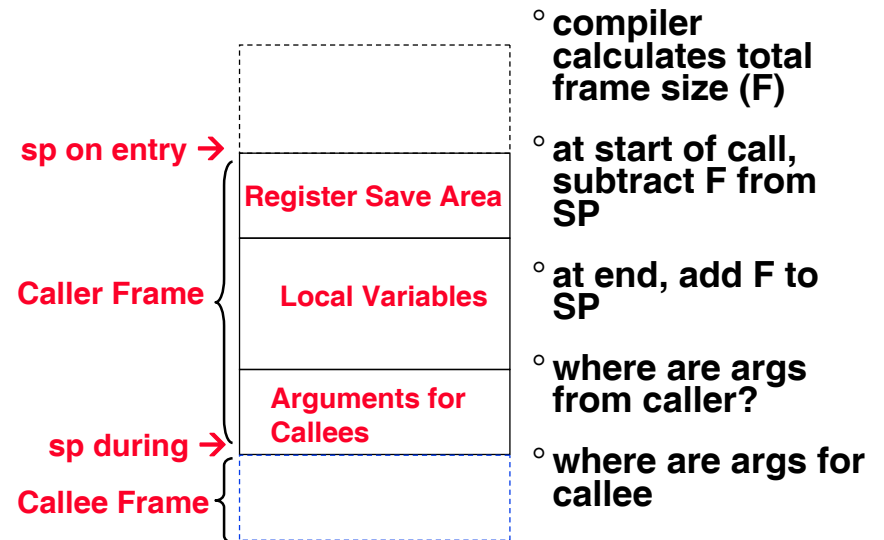


What does `sp` point to?

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Typical Structure of a Stack Frame



° compiler calculates total frame size (F)

° at start of call, subtract F from SP

° at end, add F to SP

° where are args from caller?

° where are args for callee

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“And in Conclusion ...” (#1/2)

◦ ARM Assembly language instructions

- Unconditional branches: `b, mov pc, rx, b1`

◦ Operands

- Registers (word = 32 bits); `a1 - a3, v1 - v8, ls, sb, fp, sp, lr`

“And in Conclusion ...” (#2/2)

- Functions, procedures one of main ways to give a program structure, reuse code
- `mov pc, Rn` required instruction; most add `b1` (or equivalent) to make common case fast
- Registers make programs fast, but make procedure/function call/return tricky
- ARM SW convention divides registers for passing arguments, return address, return value, stack pointer