BIRZEIT UNIVERSITY

Electrical and Computer Engineering

Computer Design Lab – ENCS4110

ARM Subroutine/procedure/function Calls

Objectives

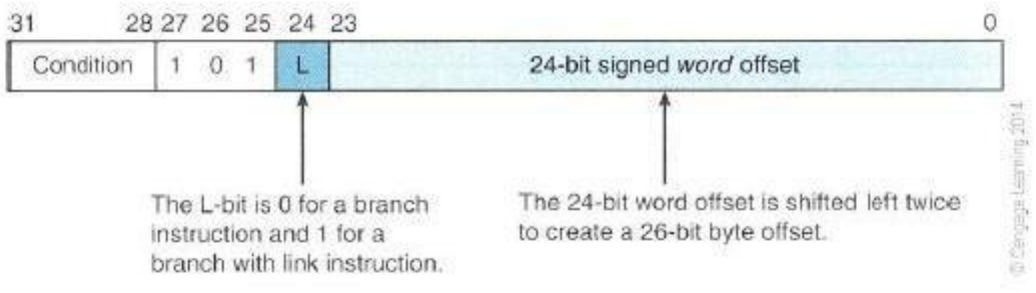
```
Explore ARM subroutine calls and implement them in Keil uVision5.
- Using   BL SUB_Name,  and MOV PC, LR  or BX  LR
- Study and using stack
```

ARM processors do not provide a fully automatic subroutine call/return mechanism like other processors. ARM's branch and link instruction, **BL**, automatically saves the return address in the register R14 (i.e. LR). We can use **MOV PC, LR** at the end of the subroutine to return back to the instruction after the subroutine call **BL SUBROUTINE_NAME**. A **SUBROUTINE_NAME** is a label in the ARM program.

ARM Unconditional and Conditional Subroutine Calls

```
  Mnemonic           Meaning
==============================================================================
  BL  SUB_A                    ; Branch to SUB_A with link save return address in R14
------------------------------------------------------------------------------
  CMP    R1, R2                ; branch conditionally
  BLLT   SUB_B                 ; if R1 < R2, then branch to SUB_B
  BLLE   SUB_C                 ; if R1 <= R3, then branch to SUB_C
  BLGT   SUB_D                 ; if R1 > R2, then branch to SUB_D
  BLGE   SUB_F                 ; if R1 >= R2, then branch to SUB_F
------------------------------------------------------------------------------
  MOV    PC, LR        ; get the control of execution back after executing
                       ; a subroutine/procedure
------------------------------------------------------------------------------
  BX  LR               ; Return to the calling function
------------------------------------------------------------------------------
  Using PROC and ENDP as a pair for procedures
```

Here is the encoding format of ARM's branch and branch-with-link instructions for your reference.


31
28 27 26 25 24 23
0
Condition
1 0 1
L
24-bit signed *word* offset
The L-bit is 0 for a branch instruction and 1 for a branch with link instruction.
The 24-bit word offset is shifted left twice to create a 26-bit byte offset.
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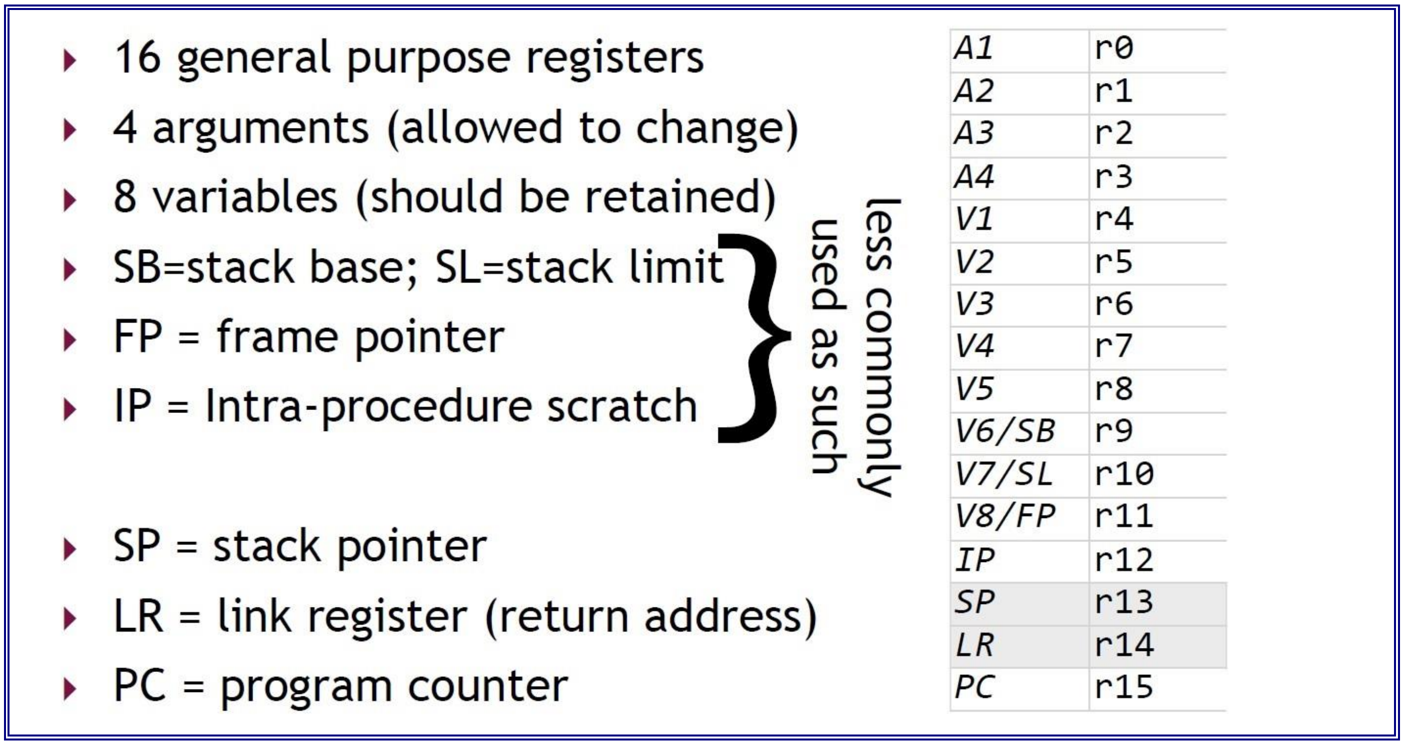
Register Use in the ARM Procudure Call Standard



- 16 general purpose registers
- 4 arguments (allowed to change)
- 8 variables (should be retained)
- SB=stack base; SL=stack limit
- FP = frame pointer
- IP = Intra-procedure scratch

less commonly used as such

- SP = stack pointer
- LR = link register (return address)
- PC = program counter

A1	r0
A2	r1
A3	r2
A4	r3
V1	r4
V2	r5
V3	r6
V4	r7
V5	r8
V6/SB	r9
V7/SL	r10
V8/FP	r11
IP	r12
SP	r13
LR	r14
PC	r15

An Example Using a Subroutine Call

```
;The semicolon is used to lead an inline documentation
;When you write your program, you could have your info at the top document lock
;For Example:
;;;;Your Name:
;;;;Student Number:
;;;;Lab#:
;;;;

;;; Directives
          PRESERVE8
          THUMB
```

```
;;; Equates
      ;; Empty
;;; Includes
      ;; Empty

;;; Vector Definitions
; Vector Table Mapped to Address 0 at Reset
; Linker requires __Vectors to be exported

          AREA    RESET, DATA, READONLY
          EXPORT  __Vectors

__Vectors
          DCD  0x20001000     ; stack pointer value when stack is empty
          DCD  Reset_Handler  ; reset vector

          ALIGN

;Your Data section
;AREA DATA

SUMP      DCD SUM
SUMP2     DCD SUM2
N         DCD 5

      AREA    MYRAM, DATA, READWRITE
SUM   DCD 0
SUM2  DCD 0


;; The program Linker requires Reset_Handler

          AREA    MYCODE, CODE, READONLY

        ENTRY
        EXPORT Reset_Handler

;;;;;Procedure definitions;;;;

SUMUP         PROC
      ADD     R0, R0, R1      ;Add number into R0
      SUBS    R1, R1, #1      ;Decrement loop counter R1
      BGT     SUMUP           ;Branch back if not done
      ;MOV    PC, LR
      BX      LR
      ENDP

;;;users main program;;;;;

Reset_Handler


      LDR     R1, N           ;Load count into R1

      MOV     R0, #0          ;Clear accumulator R0

      BL      SUMUP

      LDR     R3, SUMP        ;Load address of SUM to R3
      STR     R0, [R3]        ;Store SUM
      LDR     R4, [R3]

      MOV     R7, #8

      LDR     R5, SUMP2       ;Load address of SUM2 to R5
      STR     R7, [R5]        ;Store SUM2

      LDR     R6, [R5]


STOP
        B STOP

      END
```

Introduction to Stack

```
      The stack is a data structure, known as last in first out (LIFO).
      In a stack, items entered at one end and leave in the reversed order.
      Stacks in microprocessors are implemented by using a stack pointer
      to point to the top of the stack in memory.
      As items are added to the stack (pushed), the stack pointer is
      moving up, and as items are removed from the stack (pulled or popped),
      the stack pointer is moved down.
```

Here is a picture to show the idea of **Stack LIFO** structure.

Stack Types: ARM stacks are very flexible since the implementation is completely left to the software. Stack pointer is a register that points to the top of the stack. In the ARM processor, any one of the general purpose registers could be used as a stack pointer. Since it is left to the software to implement a stack, different implemenation choices result different types of stacks. Normally, there are two types of the stacks depending on which way the stack grows.

```
1.    Ascending Stack - When items are pushed on to the stack,
      the stack pointer is increasing.  That means the stack grows
      towards higher address.

2.    Descending Stack - When items are pushed on to the stack,
      the stack pointer is decreasing.  That means the stack is growing
      towards lower address.
```

Depending on what the stack pointer points to we can categorize the stacks into the following two types:

```
1.    Empty Stack - Stack pointer points to the location in which the next/first item
      will be stored.
      e.g. A push will store the value, and increment the stack pointer
      for an  Ascending Stack.

2.    Full Stack - Stack pointer points to the location in which the last item
      was stored.
      e.g. A pop will decrement the stack pointer and pull the value
      for an Ascending Stack.
```

So now we can have four possible types of stacks. They are

1. full-ascending stack,
2. full-descending stack,
3. empty-ascending stack,
4. empty-descending stack.

They can be implemented by using the register load and store instructions.

Here are some instructions used to deal with stack:

Push registers onto and pop registers off a full-descending stack.

```
      Examples:
      PUSH {R0, R4-R7}       ;Push R0, R4, R5, R6, R7 onto the stack
      PUSH {R2, LR}          ;Push R2 and the link register onto the stack
      POP  {R0, R6, LR}      ;Pop R0, R6, and LR from the stack
      POP  {R0, R5, PC}      ;Pop R0, R5, and PC from the stack
                             ;then branch to the new PC
============================================================================
      Reference:  Cortex-M3 Devices Generic User Guide  Page 3-29 to 3-30.
```

Subroutine and Stack

```
      A subroutine call can be implemented by pushing the return
      address on the stack and then jumping to the branch target
      address.  When the subroutine is done, remember to pop out
      the saved information so that it will be able to return to
      the next instruction immediately after the calling point.
```

An Example of Using Stack

```
;; Put your name and a title for the program here
;;

;;; Directives
            PRESERVE8
            THUMB


;;; Equates
;;; The EQU directive gives a symbolic name to a numeric constant,
;;; a register-relative value or a PC-relative value.
;;; Use EQU to define constants.

INITIAL_MSP   EQU     0x20001000     ; Initial Main Stack Pointer Value
                      ; Allocating 1000 bytes to the stack as it grows down.
                      ; RAM starts at address 0x20000000


; Vector Table Mapped to Address 0 at Reset
; Linker requires __Vectors to be exported

            AREA    RESET, DATA, READONLY
            EXPORT  __Vectors

__Vectors     DCD     INITIAL_MSP    ; stack pointer value when stack is empty
              DCD     Reset_Handler  ; reset vector
              ALIGN

; The program
; Linker requires Reset_Handler

            AREA    MYCODE, CODE, READONLY

                 ENTRY
                 EXPORT     Reset_Handler

                 ALIGN
;;; Define Procedures

function1     PROC         ;Using PROC and ENDP for procedures
      PUSH    {R5,LR}      ;Save values in the stack

      MOV     R5,#8        ;Set initial value for the delay loop

delay
      SUBS    R5, R5, #1
      BNE     delay

      POP     {R5,PC} ;pop out the saved value from the stack,
                      ;check the value in the R5 and if it is the saved value


      ENDP

;;;;;;;user main program;;;;;;;

Reset_Handler
```

```
      MOV     R0, #0x75
        MOV   R3, #5
      PUSH    {R0, R3}         ;Notice the stack address is 0x200000FF8
        MOV   R0, #6
        MOV   R3, #7
      POP     {R0, R3}         ;Should be able to see R0 = #0x75 and R3 = #5 after pop



Loop

      ADD     R0, R0, #1
      CMP     R0, #0x80
      BNE     Loop


      MOV     R5, #9  ;; prepare for function call


      BL      function1

      MOV     R3, #12

stop
        B     stop


        END
```

Lab work:

Program#1:

Write an ARM assembly language program **CountVowelsTwo.s** to count how many vowels and how many non-vowels are in the following string.

```
      "ARM assembly language is important to learn!",0
```

You are required to implement this by using a subroutine to check if a character is vowel or not, and count the vowels and non-vowels in the calling function.

Recommendations for writing the program:

- Put the string in the memory by using DCB.
- Use R0 to hold the address of a character in the string.
- Use R2 to be the counter for vowels.
- Use R3 to be the counter for non-vowels.
- Build the program, debug until there is no error.
- Make a screenshot to show that the build is successful with no errors.
- Run the program step by step and see how values are changing in the registers. OR just run the program and see the final results in the register R2 and R3.

- Make a screenshot to capture the results in your designated registers.

You will hand in the following:

1. The source code in the file **CountVowelsTwo.s**
2. The screenshot (print screen) to show the program has been successfully built
3. The screenshot showing the number of vowels in R2 and non-vowels in R3.

Program#2:

Write an ARM assembly language program that will have a user defined function/procedure **factorial** to calculate the factorial for a given number.

```
      For example:
      The factorial of 5 is 5! = 5 x 4 x 3 x 2 x 1
      The factorial of 0 is defined as 0! = 1
      In general, n! = n x (n-1)!, where n is a positive integer.
      If we write f(n) = n!, then f(n) = n f(n-1).
      It is a recursive function.

      Please implement it by using stack.
      When you test it, you can use relatively smaller numbers such as 3, 4, 5, or 6.

      For marking purpose, put the input number in the R1 and
      put your final result in the register R0 or
      indicate it specifically in your hand-in assignment.
```

You will hand in the following:

1. The source code in the file **Factorial.s**
2. The screenshot (print screen) to show the program has been successfully built
3. The screenshot showing the input number in R1 and the result in R0