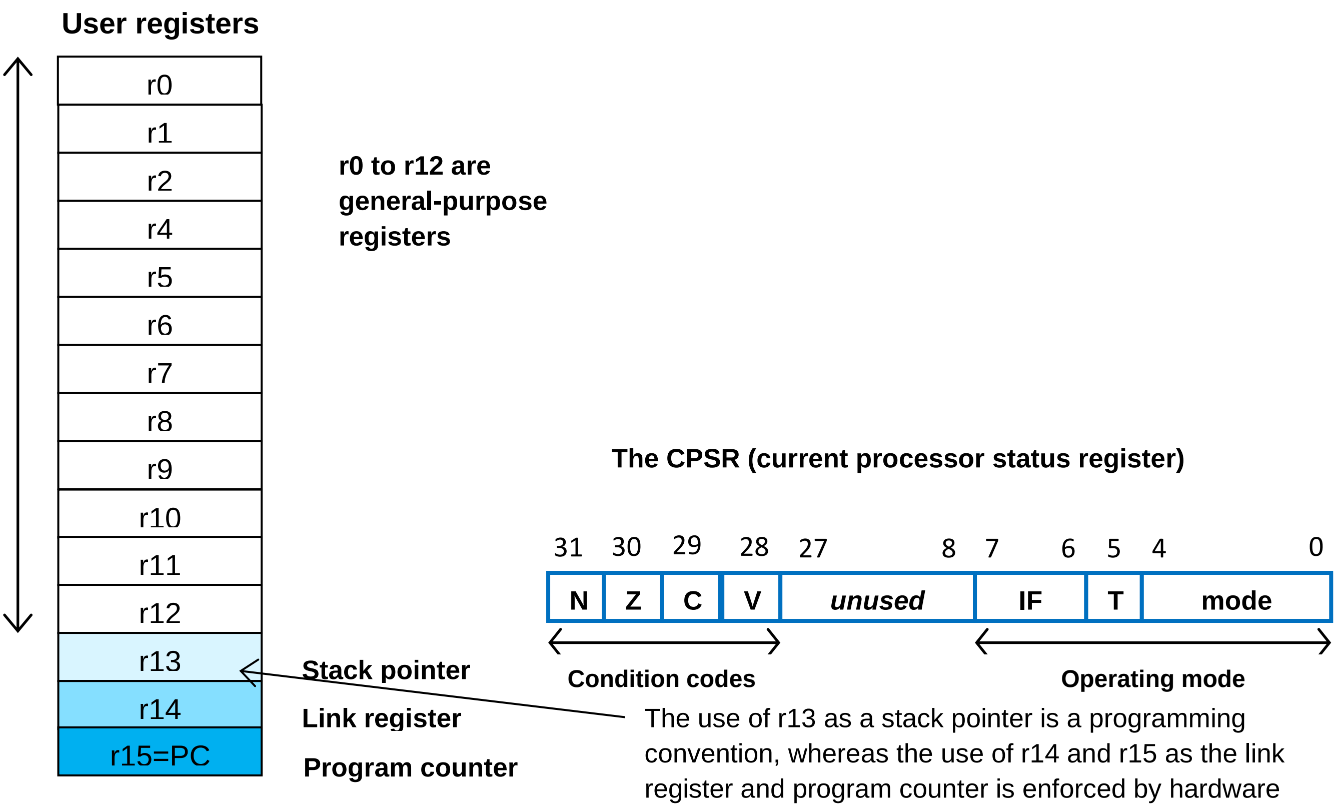
Lab work #3
Addressing modes in ARM processors

1. **Lab work's objective:** To explore ARM addressing modes and implement them in Keil uVision5

2. **Preparation**

2.1. ARM's Flow Control Instruction

As mentioned in the previous assignment, ARM has 16 programmer-visible registers and a *Current Program Status Register*, CPSR.
Here is a picture to show the **ARM register set**.



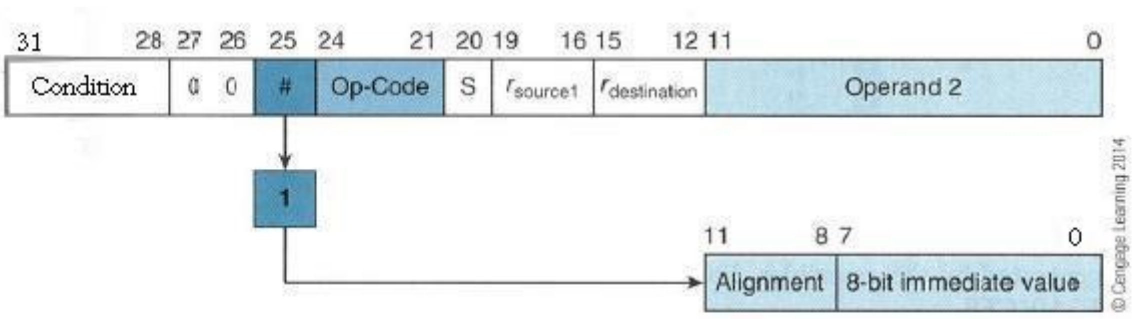

```
R0 to R12 are the general-purpose registers.
R13 is reserved for the programmer to use it as the stack pointer.
R14 is the link register, which stores a subroutine return address.
R15 contains the program counter and is accessible by the programmer.

Condition codes flags in CPSR:
N - Negative or less than flag
Z - Zero flag
C - Carry or borrow or extended flag
V - Overflow flag
The least-significant 8-bit of the CPSR are the control bits of the system.
The other bits are reserved.
```

2.2. Summary of ARM addressing Modes

There are different ways to specify the address of the operands for any given operations such as load, add or branch. The different ways of determining the address of the operands are called addressing modes. In this lab, we are going to explore different addressing modes of ARM processor and learn how all instructions can fit into a single word (32 bits).

Name	Alternative Name	ARM Examples
Register to register	Register direct	MOV R0, R1
Absolute	Direct	LDR R0, MEM
Literal	Immediate	MOV R0, #15 ADD R1, R2, #12
Indexed, base	Register indirect	LDR R0, [R1]
Pre-indexed, base with displacement	Register indirect with offset	LDR R0, [R1, #4]
Pre-indexed, autoindexing	Register indirect pre-incrementing	LDR R0, [R1, #4]!
Post-indexed, autoindexing	Register indirect post-incrementing	LDR R0, [R1], #4
Double Reg indirect	Register indirect Register indexed	LDR R0, [R1, R2]
Double Reg indirect with scaling	Register indirect indexed with scaling	LDR R0, [R1, r2, LSL #2]
Program counter relative		LDR R0, [PC, #offset]

2.3. Literal Addressing



Examples	Meaning
CMP r0, #20	MOV R0, R1
ADD r1,r2,#10	LDR R0, MEM
MOV r1,#30	MOV R0, #15 ADD R1, R2, #12
MOV r1,#0xFF	LDR R0, [R1]
MOV r2,#0xFF0000FF	LDR R0, [R1, #4]
AND r0,r1,#0xFF000000	LDR R0, [R1, #4]!
CMN r0,#6400	; update the N, Z, C and V flags
CMPGT SP,r7,LSL #2	; update the N, Z, C and V flags

2.4. Register Indirect Addressing

Register indirect addressing means that the location of an operand is held in a register. It is also called indexed addressing or base addressing.

Register indirect addressing mode requires three read operations to access an operand. It is very important because the content of the register containing the pointer to the operand can be modified at runtime. Therefore, the address is a variable that allows the access to the data structure like arrays.

- Read the instruction to find the pointer register
- Read the pointer register to find the operand address
- Read memory at the operand address to find the operand

Some examples of using register indirect addressing mode:

```
LDR    R2, [R0]     ; Load R2 with the word pointed by R0
STR    R2, [R3]     ; Store the word in R2 in the location pointed by R3
```

2.5. Register Indirect Addressing with an Offset

ARM supports a memory-addressing mode where the effective address of an operand is computed by adding the content of a register and a literal offset coded into load/store instruction. For example,

Instruction	Effective Address
`LDR r0,[r1,#20]`	`r1+20 ; loads r0 with the word pointed at by r1+20`

2.6. ARM's Autoindexing Pre-indexed Addressing Mode

This is used to facilitate the reading of sequential data in structures such as arrays, tables, and vectors. A pointer register is used to hold the base address. An offset can be added to achieve the effective address. For example,

Instruction	Effective Address
`LDR r0,[r1,#4]!`	`r1+4 ; loads r0 with the word pointed at by r1+4` `then update the pointer by adding 4 to r1`

2.7. ARM's Autoindexing Post-indexing Addressing Mode

Register R15 is the program counter. If you use R15 as a pointer register to access operand, the resulting addressing mode is called PC relative addressing. The operand is specified with respect to the current code location. Please look at this example,

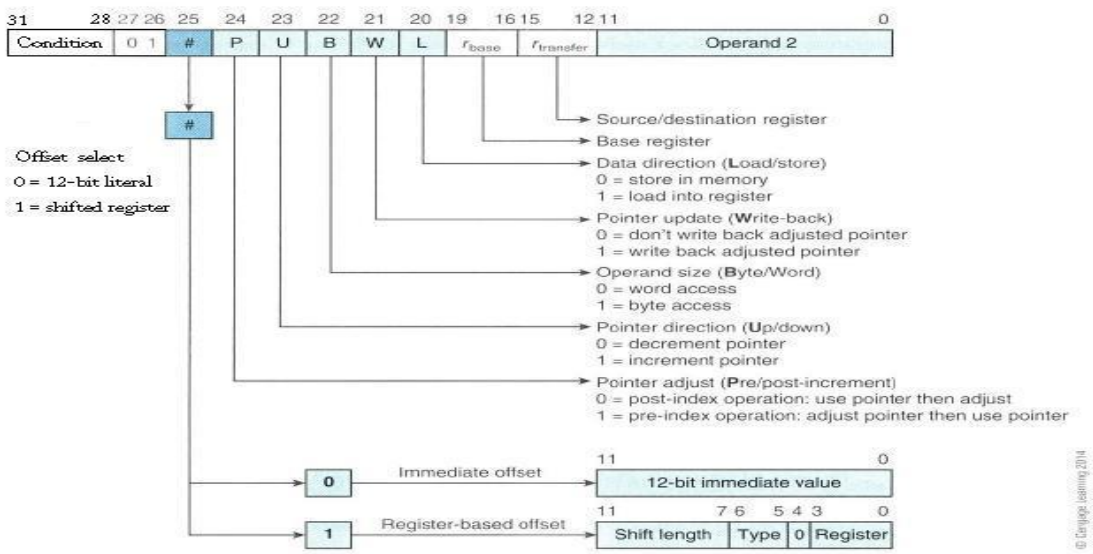
Instruction	Effective Address
`LDR r0,[r15,#24]`	`r15+24 ; loads r0 with the word pointed at by r15+4`

2.8. ARM's Load and Store Encoding Format

The following picture illustrates the encoding format of the ARM's load and store instructions, which is included in the lab material for your reference. Memory access operations have a conditional execution field in bit 31, 03, 29, and 28. The load and store instructions can be conditionally executed depending on a condition specified in the instruction. Now look at the following examples:

```
CMP     r1,r2
LDREQ r3,[r4]
LDRNE r3,[r5]
```

2.9. Encoding Format of ARM's load and store instructions



2.10. Summary of ARM's Indexed Addressing Modes

Addressing Mode	Assembly Mnemonic	Effective address	Final Value in r1
Pre-indexed, base unchanged	LDR R0, [R1, #d]	r1 + d	r1
Pre-indexed, base updated	LDR R0, [R1, #d]!	r1 + d	r1 + d
Post-indexed, base updated	LDR R0, [R1], #d	r1	r1 + d

2.11. An Example Program of Using Post-indexing Mode

```
; The semicolon is used to lead an inline documentation
;
; When you write your program, you could have your info at the top document block
; For Example:  Your Name, Student Number, what the program is for, and what it does etc.
;
;            This program will find the sum of an array.

            AREA   MYCODE, CODE, READONLY
            ENTRY

            LDR R1, N   ; load size of array -
                        ; a counter for how many elements are left to process
            LDR R2, POINTER  ; load base pointer of array
            MOV R0, #0       ; initialize accumulator
LOOP
            LDR R3, [R2], #4 ; load value from array,
                             ; increment array pointer to next word
            ADD R0, R0, R3   ; add value from array to accumulator
            SUBS R1, R1, #1  ; decrement work counter
            BGT LOOP         ; keep looping until counter is zero
            LDR R4, SUMP     ; get memory address to store sum
            STR R0, [R4]     ; store answer

            LDR R6, [R4]     ; Check the value in the SUM
STOP        B      STOP

            AREA   MYCODE, DATA, READWRITE
SUM         DCD    0
SUMP        DCD    SUM

N           DCD    5
NUM1        DCD    3, -7, 2, -2, 10
POINTER     DCD    NUM1

            END              ; End of the program
```

2.12. Another Example

```
; The semicolon is used to lead an inline documentation
;
; When you write your program, you could have your info at the top document block
; For Example:  Your Name, Student Number, what the program is for, and what it does etc.
;
;           This program will count the length of a string.
      AREA   MYCODE, CODE, READONLY

      LDR    R0, = string        ; Load the address of string1 into the register R0
      MOV    R1, #0        ; Initialize the counter counting the length of string
loopCount
      LDRB   R2, [R0], #1        ; Load the character from the address R0 contains
                                 ; and update the pointer R0
                                 ; using Post-indexed addressing mode
      CMP    R2, #0
      BEQ    countDone           ; If it is zero...remember null terminated...
                                 ; You are done with the string. The length is in R1.
      ;ADD   R0, #1              ; Otherwise, increment index to the next character
      ADD    R1, #1              ; increment the counter for length
      B      loopCount
countDone
      B      countDone

             AREA  MYCODE, CODE, READWRITE
string       DCB   "Hello world!",0
             END                 ; End of the program
```

3. Lab Assignment

3.1. Assignment #1:

Write an ARM assembly language program **AddGT.s** to add up all the numbers that are great than 5 in the number array NUM1. Look at the following given code for more details and complete it.

```
; The semicolon is used to lead an inline documentation
;
; When you write your program, you could have your info at the top document
block
; For Example:  Your Name, Student Number, what the program is for, and what it
does etc.
             AREA  MYCODE, CODE, READONLY
             ENTRY

;     User Code Start from the next line             ;

;     Please complete the program to add up all the
;     numbers in the array NUM1 that are greater than 5.
;     Put the sum in the register R0

STOP         B     STOP

             AREA  MYCODE, CODE, READWRITE
SUM          DCD   0
SUMP         DCD   SUM
N            DCD   7
NUM1         DCD   3, -7, 2, -2, 10, 20, 30
POINTER      DCD   NUM1

             END                 ; End of the program
```

You will hand in the following:

1. The source code in the file **AddGT.s**
2. The print out of the screen shot (print screen) to show the program has been successfully built
3. The print out of the screen shot showing the sum in R0.

3.2. Assignment#2:

Write an ARM assembly language program **Min-Max.s** to find the maximum value and the minimum value in the number array NUM1. Look at the following given code for more details and complete it.

```
            AREA  MYCODE, CODE, READONL
            ENTRY

;     User Code Start from the next line              ;

;     Add code below to find the maximum value and
;     the minimum value in the number array NUM1.
;     You can use the example in the notes as a reference.
STOP        B     STOP

            AREA  MYCODE, CODE, READWRITE
Max         DCD   0
MaxP        DCD   Max
Min         DCD   0
MinP        DCD   Min

N           DCD   12
NUM1        DCD   3, -7, 2, -2, 10, 20, 30, 15, 32, 8, 64, 66
POINTER     DCD   NUM1

            END               ; End of the program
```

You will hand in the following:

1. The source code in the file **Min-Max.s**
2. The print out of the screen shot (print screen) to show the program has been successfully built
3. The print out of the screen shot showing the Min in R5 and the Max in R6.