Lecture 7

Assembler Directives, Arrays & Indexed Mode

Before We Start

Quiz 3 First coding assignment – due Wednesday September 20

– Finally, no more Carmen quizzes until the final exam

- Will post by the end of tomorrow
- Simple coding assignment, need CCS and Launchpad

Note: CCS is available for macOS and Linux too!

If you have trouble with CCS: office hours, discord, or email

You will need to do lots of **screenshots** for this class

- Screenshots of code, screenshots of memory views
- All screenshots in light mode please !!
- Try: Right click on

Joke of the Day

Why do programmers prefer dark mode?

Because light attracts bugs.

Last Time

Five instructions

```
mov.w    src, dst
add.w    src, dst
rra.w    dst
jmp      label
nop
```

These instructions also have a byte version

Three addressing modes

- **Immediate data:** `src` is the value given after **#**
- **Absolute address:** the address of the `src` or `dst` is given after **&**
- **Register mode:** `src` or `dst` is one of the core registers **R**0 – **R**15

First Code

First task: Find the average value of the set of numbers {2, -43, 7, 19}

```
;-------------------------------------------------------------
; Main loop here
;-------------------------------------------------------------

            mov.b   #2, R4          ; R4 <- 2
            add.b   #-43, R4        ; R4 <- R4 + (-43)
            add.b   #7, R4          ; R4 <- R4 + 7
            add.b   #19, R4         ; R4 <- R4 + 19

            rra.b   R4              ; R4 <- R4/2
            rra.b   R4              ; R4 <- R4/2

main:       jmp     main
            nop
```

This is a screenshot from CCS
I will ask you to submit screenshots of your code, your memory browser, registers etc.

Today we will redo this

- Introducing **assembler directives**
- ***Variables*** and ***arrays***
- **More addressing modes**

Assembler Directives

Assembler directives supply program data and control the assembly process

We will use them to

- Assemble code and data into specified sections

```
.data    ; Everything after this goes to RAM
.text    ; Everything after this goes to FRAM
```

- Reserve space in memory (initialized to zero)

```
.space 6  ; Reserve 6 bytes of space
```

- Initialize memory to desired values

```
.word 0xB, 0xC     ; initialize words
.byte -1, 5, 3     ; initialize bytes
```

- Define global variables

```
array:     .word 0x1, 0x2, 0x3, 0x4
```

- Define symbolic constants – no memory reserved

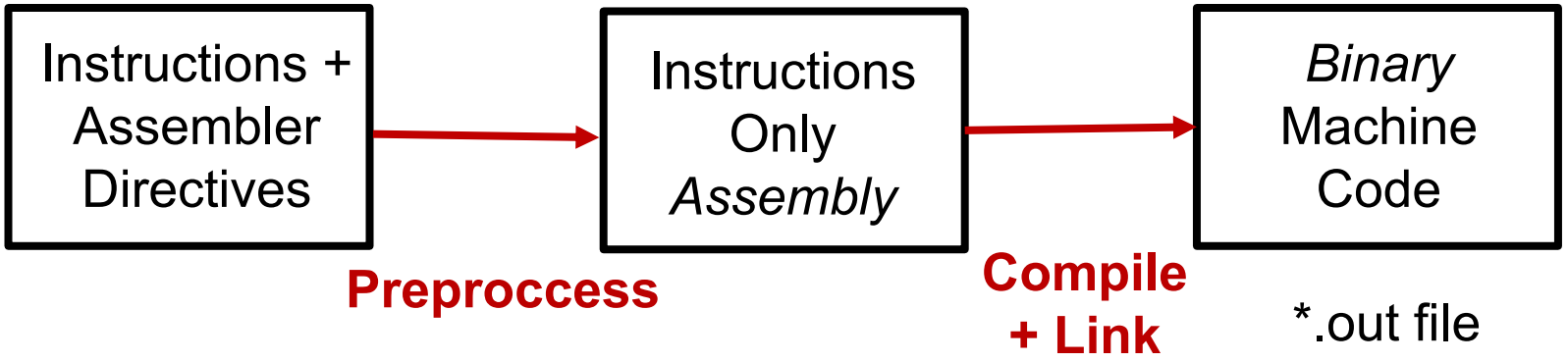
```
scon:      .set 4
```

Assembly to Machine Code

The hammer icon  on CCS initiates the **build** of the code

Build = Preprocess + Compile + Link

Simplified Picture



The bug icon  uploads the binary machine code to the FRAM and also initiates memory in RAM and FRAM (per preprocessor directions)

Assembly to Machine Code

Assembly Code	Machine Code	Address of Instruction
`mov.w #__STACK_END,SP`	`4031 2400`	`0x4400`
`mov.w #WDTPW|WDTHOLD,&WDTCTL`	`40B2 5A80 015C`	`0x4404`
`mov.b #2, R4`	`4364`	`0x440a`
`add.b #-43, R4`	`5074 FFD5`	`0x440c`
`add.b #7, R4`	`5074 0007`	`0x4410`
`add.b #19, R4`	`5074 0013`	`0x4414`
`rra.b R4`	`1144`	`0x4418`
`rra.b R4`	`1144`	`0x441a`
`jmp main`	`3FFF`	`0x441c`
`nop`	`4303`	`0x441e`

Memory usage reported after code upload

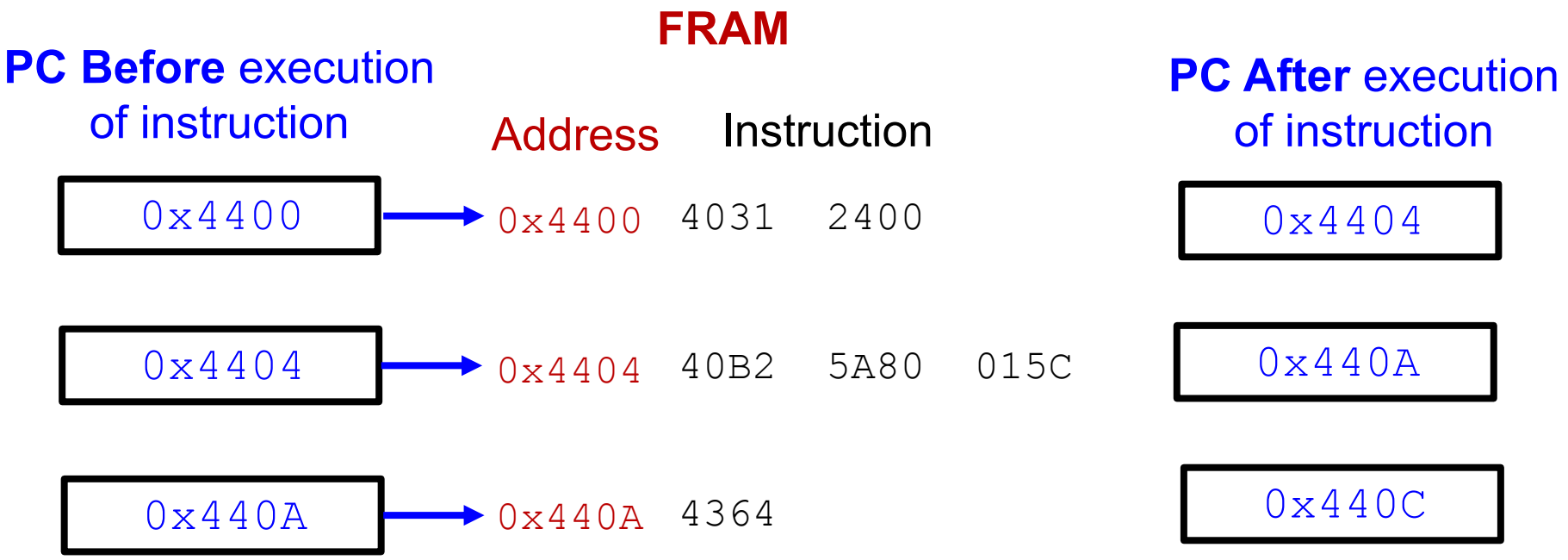
The Program Counter R0/PC

The core register R0 is the **Program Counter PC**

The **program counter points to the next instruction to be executed**

i.e.,

when we look into the PC register we see the address of the next instruction



Variables in MSP430 Assembly

We will use assembler directives to reserve and initialize data in memory

We will use labels to name *variables* and use **absolute address mode (&)** or **symbolic address mode**

Task: Define word variables x = 5 and y = 8 in RAM and reserve space for word variable sum

```
        .data
x:      .word   5
y:      .word   8
sum:    .space  2
```

A label is simply a name for an address

```
x   = 0x1C00
y   = 0x1C02
sum = 0x1C04
```

Task: Add x and y and store in sum

Symbolic address mode

```
mov.w   x, sum
add.w   y, sum
```

Arrays in MSP430 Assembly

There is no actual array construct in assembly

We will emulate arrays using assembler directives and labels

```
                  array1    array1+2   array1+4
array1:  .word    0x0100,   0x0200,    0x0300
```

address

value

```
                  array2    array2+1   array2+2
array2:  .byte    0x01,     0x02,      0x03
```

address

value

We will have to be careful when working with byte vs word arrays

Indexed Mode of Addressing

Syntax of **indexed mode**

```
array1: .word  0x0100,  0x0200,  0x0300

        mov.w  array1(R4), R5        ; syntax is x(R)
                                     ; x is the array name
                                     ; R is a core register
                                     ; copies from x + (@R)
```

Offset is stored in R

e.g.:

```
        mov.w  #2, R4
        mov.w  array1(R4), R5
```

same as

```
        mov.w  &array1+2, R5
```

Arrays in MSP430 Assembly

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We will emulate arrays using assembler directives and labels

```
                  array1   array1+2  array1+4
array1: .word   0x0100,   0x0200,   0x0300
```

address

value

```
                  array2   array2+1  array2+2
array2: .byte   0x01,     0x02,     0x03
```

address

value

We will have to be careful when working with byte vs word arrays

Task: Find the sum of the numbers in each array.

Indexed Mode and **Byte** Arrays

```
                array2   array2+1  array2+2
array2:  .byte  0x10,    0x20,     0x30

         mov.b  &array2, R5
         add.b  &array2+1, R5
         add.b  &array2+2, R5
```

Same as:

```
         mov.w  #0, R4              ; R4 = 0 will be the index
         mov.b  array2(R4), R5      ; R5 = array2[R4]
         inc.w  R4                  ; R4++
         add.b  array2(R4), R5      ; R5 += array2[R4]
         inc.w  R4                  ; R4++
         add.b  array2(R4), R5      ; R5 += array2[R4]
```

Indexed Mode and **Word** Arrays

```
                array1   array1+2   array1+4
array1:  .word  0x0100,   0x0200,   0x0300

         mov.w  &array1, R5
         add.w  &array1+2, R5
         add.w  &array1+4, R5
```

Same as:

```
         mov.w  #0, R4              ; R4 = 0 will be the index
         mov.w  array2(R4), R5      ; R5 = array2[R4]
         inc.w  R4                  ; R4++
         inc.w  R4                  ; R4++
         add.w  array2(R4), R5      ; R5 += array2[R4]
         inc.w  R4                  ; R4++
         inc.w  R4                  ; R4++
         add.w  array2(R4), R5      ; R5 += array2[R4]
```

More Instructions

MSP430 assembly has many **emulated instructions**

An emulated instruction is a shorthand notation for the programmer
The assembler replaces it with a regular instruction
You do not need to use any, but they make life easier – your choice
e.g.

`inc.w R4`	same as	`add.w #1, R4`
`incd.w R4`	same as	`add.w #2, R4`
`clr.w R4`	same as	`mov.w #0, R4`