

# COE 205: Computer Organization & Assembly Language Introductory Experiment-B

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## Introduction

A computer system consists mainly of three components: a **Central Processing Unit (CPU)**, a **memory** and **Input/Output (I/O) devices**. These three components are interconnected by a **bus system**. A conceptual arrangement of such system can be seen in Fig 1.

As an assembly programmer, you need to know some basic information about the hardware you are programming. In this experiment, you will learn the basics of the above-mentioned components and you will be able to extract some information about them devices from your PC. You will also be able to comprehend the extracted information and use them to get more information about your PC. The theme of this experiment is to see how your program runs and affects those components.

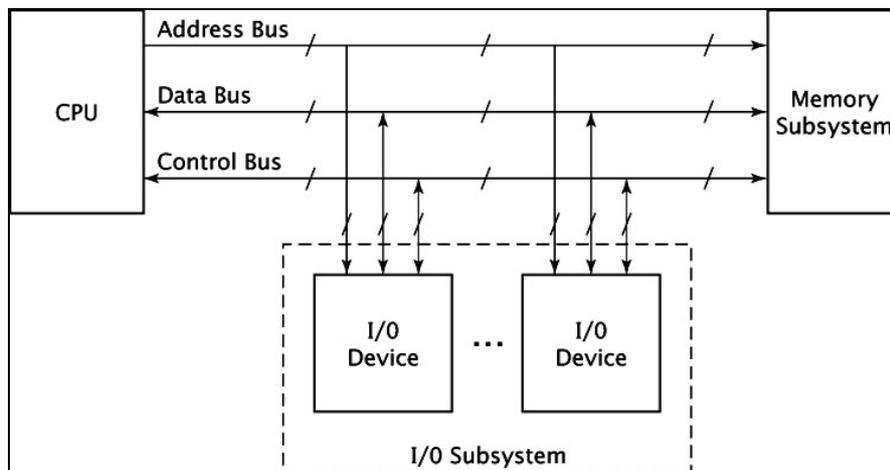


Fig 1: Abstract Computer System.

## The Bus System

The bus is simply a set of wires. The bus system consists of three buses: a **data bus**, an **address bus** and a **control bus**. I will use the term "bus system" when referring to the three buses together and the term "bus" to refer to a single bus. The bus system connects the CPU, memory and I/O devices. The term **bus cycle** refers to a single transaction on the bus. As examples, memory read, memory write and I/O read and I/O write are all bus transactions or bus cycles.

The data bus is used to transfer data between the CPU and memory or the CPU and the I/O devices. Notice in Fig.1 that the data bus and the control are **bidirectional** which means that data can move in both directions. The address bus however is **unidirectional**. The width of the data bus determines the size of the data that can be transferred at one time. For example, the 8086 has a 16-bit data bus, which means we can transfer at most 16-bit in one bus cycle. If we have 32-bit data in the CPU and we would like to move it to memory, then we need two bus cycles.

The width of the address bus determines the amount of the memory accessible by the CPU. For example, the 8086 has a 20-bit address bus, which means that we can access up to  $2^{20}$ , or 1 MB, of memory. The address bus is used by the CPU to indicate the location the CPU would like to read from or write into.

The control bus is used to indicate the type of the requested operation. For example if the CPU would like to read from memory, then it places a memory read on the control bus. In case of I/O read on the other hand, it places an I/O read and so on.

Processor	Estimated Clock Rate	Data Bus Width	Address Bus Width
8086	4.7 MHz	16-bit	20-bit
8088	4.7 MHz	8-bit	20-bit
80286	8 MHz	16-bit	24-bit
80386	40 MHz	32-bit	24-bit (Also 32-bit)
80486	75 MHz	32-bit	32-bit
Pentium	3 GHz +	64-bit	32-bit (Also 36-bit)

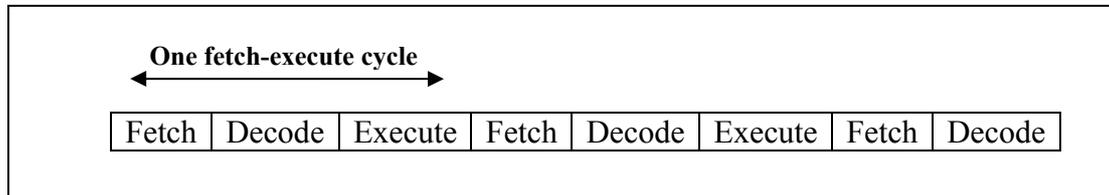
**Table 1: A Comparison Between Different Processors**

## The Central Processing Unit (CPU)

The CPU -also called the processor- is the heart of any computer system. The CPU is driven by a **clock** that synchronizes all events inside the computer system. Consider a Pentium 4 with 2 GHz clock. Such a clock generates  $2 \times 10^9$  clock cycles per a second, this quantity is called the **clock speed** or **clock frequency** ( $f$ ). Each clock cycle takes a period ( $T$ ) that is calculated as

$$T = \frac{1}{f} = \frac{1}{2 \times 10^9} = 0.5 \text{ ns}$$

The CPU fetches instructions and data from memory, decodes the instructions, executes them and finally writes the results back into memory. This process is repeated forever and is called the **fetch-execute** cycle.



**Fig 2: Fetch-Execute Cycle.**

Fetching an instruction means reading it from memory. To do this, the CPU places the address of the memory location it wishes to read. Place a memory read on the control bus. The memory responds by placing the data on the data bus. The CPU in turn reads the data from the data bus.

Decoding the instruction means interpreting the meaning of the instruction. By looking into the **opcode** which is a part of the binary representation of the instruction, the CPU can recognize whether the require operation is an addition, subtraction, multiplication etc.

Executing the instruction is done by special hardware inside the CPU. The CPU contains an Arithmetic and Logic Unit (ALU) that performs arithmetic operations such as addition and multiplication, and logical operations such as AND and XOR. The CPU also conations a control unit the controls the timing of the events required to complete certain operation.

The CPU contains a set of registers. Some registers are used to store data temporarily while executing instructions. Examples of such registers are general purpose registers such as AX, BX. Other registers are used to control the CPU operations. An example is the IP register which tells the CPU about address of the next instruction to be executed. Others registers include the flag register that contains information about the current state of the CPU. In the 8086, registers are 16-bit, while in the Pentium they are 32-bit. Refer to the textbook for more details about registers.

## **Memory**

Memory stores data and instruction required to manipulate the data. Two operations are provided by the memory. The first operation is the **read operation**, in which the content of a specific location in memory, determined by the value on the

address bus, is read and placed on the data bus. The other operation is the **write operation** where a value that is available on the data bus is written on a specific location in memory indicated on the address bus.

As we said earlier, the size of the addressable memory is determined by the size of the address bus. For most systems, the available memory is less than the addressable one. Also the memory differentiates between a read and write operation by reading the value of control bus.

## I/O Devices

The I/O devices work as an interface between the outer world and computers. These devices allow human to interact with computers in a convenient way. Examples of such devices are monitor, mouse, keyboard and printer. These devices are connected with the computer using different interfaces. Examples of such interfaces include serial port, parallel port, Universal Serial Bus (USB). These I/O ports are, in turn, interfaced to the system bus through an I/O controller.

## Using the CodeView

The CodeView (CV) is a useful utility that allows you to trace your program and watch the status of your computer system while running your program. You will use this tool to debug your program whenever needed.

```
TITLE "programB1"
.MODEL SMALL
.STACK 100
.DATA
    A      DB      2
    B      DB      3
    C      DB      4
.CODE
    MOV    AX,@DATA    ; 1
    MOV    DS,AX       ; 2

    MOV    AL,B        ; 3
    MOV    BL,A        ; 4
    ADD   AL,BL        ; 5
    ADD   C,AL         ; 6

    MOV    AX,4C00H    ; 7
    INT   21H         ; 8
END
```

**Fig 3: progB1**

Before you start the steps below, write **programB1** that appears in Fig 3 using a text editor and save it as **progB1.asm** in the directory you created in the last lab. Also,

notice the number in front of each instruction because it will be used as a reference in the coming paragraphs.

After you save the program, assemble it and link it as you have learned in the previous experiment. You should have an .exe file in your directory corresponding to the same program.

### Running the CodeView

- Go to the Start> Programs> Masm 611> Masm Prompt.
- You will have the command prompt coming up, change the directory to the directory containing your program.
- Write

**Z:>COE205>LAB2> cv progB1**

and press Enter.

- You will get the following screen

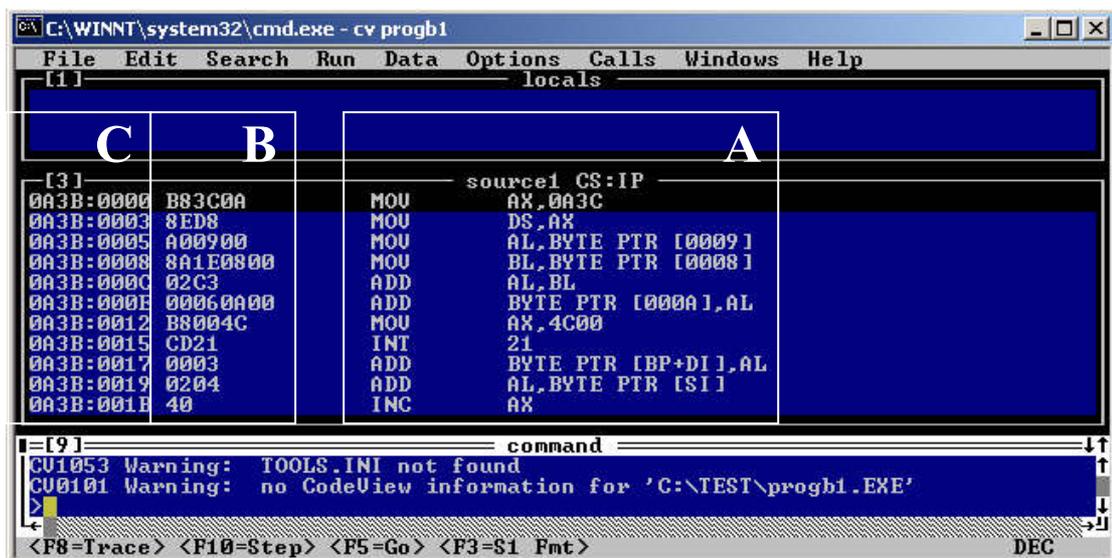


Fig 4: CodeView Main Screen.

Below, we will discuss the three parts that appear in the source window as in Fig 4.

**NOTE: the values and addresses given below may change when you run the CV on different machines; this is due to the operating system memory management. Also, note that all the values given are in hexadecimal.**

#### A: Source Code

This part shows the assembly language program. Each instruction appears in one line. The instruction that is black-highlighted is the instruction that is going to be

executed next. For instance, in Fig 4 the instruction “MOV AX,0A3C” is the next instruction to be executed.

Type of Instruction	Example
No Operands	CLD
One Operand	INC AX
Two Operands	MOV AX, BX

**Table 2: Type of Instructions and Examples**

An Assembly language instruction may have zero, one or two operands. Example of each can be show in the Table 2. In case of two-operand instructions, we call the right-hand operand the **source** left-hand operand the **destination**. For example, the MOV instruction copies the value of the destination to the source. In instruction#2, the value of the register AX which is the source is copied into the register DX which is the destination.

Note that some instructions are viewed in a different from than the source code. For example, the instruction “MOV AX, @Data“ has been replaced with “MOV AX,0A3C”. In reality, there is no difference; the value 0A3C is nothing but the data segment address for this program after its loaded by the MS-DOS operating system. Another Example is the third instruction “MOV AL, B”, which has been replaced by “MOV AL, BYTE PTR[0009]”. Where BYTE PTR[0009] is nothing but a pointer to the offset of the variable “B”. In this case, variable “B” has been stored in the location with offset 0009H in the data segment.

## **B: Machine Code**

An instruction represented as a machine code is shown in part B. This shows how exactly the instruction is represented inside the memory. Generally, the first byte of the instruction is called the *opcode* and it indicates operation (MOV, ADD, .etc) and the addressing mode. For example, see the two instructions below.

	Machine Code	Assembly Code
1	B83C0A	MOV AX, 0A3C
2	B8004C	MOV AX, 4C00

Notice, that the higher bytes are the same (B8) since both instructions involves moving an immediate value into a word register. The lower byte however, carries the value to be loaded into the register in reverses order.

Different instructions have different length depending on their type. To see that, compare the following two instructions taken from the code in Fig 3.

	Machine Code	Assembly Code	Length (Bytes)
1	B83C0A	MOV AX, 0A3C	3
2	8ED8	MOV DS,AX	2

This difference is made to get better efficiency in performance and space making the instructions that are used more often shorter in length. More details about the instruction formatting can be found in the textbook.

### C: Instruction Address

Part C shows the address of the instruction in the data segment. Because instructions differ in lengths, they occupy different parts of memory. The address is divided into two parts, *a segment address* and *an offset*. The address looks like

#### Segment Address : Offset

The segment address in this case represents the *code segment* (CS). For example, instruction#6 “ADD C,AL” has the address 0A3B:000E. Which means it is stored in segment 0A3B of the code segment. The offset indicates a specific byte inside the segment.

The 8086 divides the memory into segments each is 64K Byte. If you calculate the number of bits required to address such a memory you will find it 16-bit (2 Byte) and this is why we have the offset as 2 bytes long.

Think of the memory as a country. Then, the segments correspond to cities inside the country. A segment address corresponds to a postal code of a city. As each city contains many houses, each segment is divided into bytes. Like we use the P.O. Box to address a house or an address in a city, we use the offset address a byte inside a segment.

Let us continue with our example. We saw that instruction#5 starts at address 0A3B:000E. Since the instruction is 4 bytes long, it ends at address 0A3B:0011. Similarly, instruction#6 starts at address 0A3B:0012. Note, that all instructions have the same segment address.

## How to step your program

In order to execute the next instruction press F10. The cursor will move one position down. You can also put a break point and make the program runs till this break point.

To do this:

- 1- Highlight the instruction that you would like to stop at.
- 2- Go to **Data** menu and chose **Set Breakpoint**.
- 3- Press F5.

In order to reset the program, go to **Run** menu and select **Restart**.

## Viewing the Registers Window

Another important window is the registers window. You can view it by Clicking Alt+7.

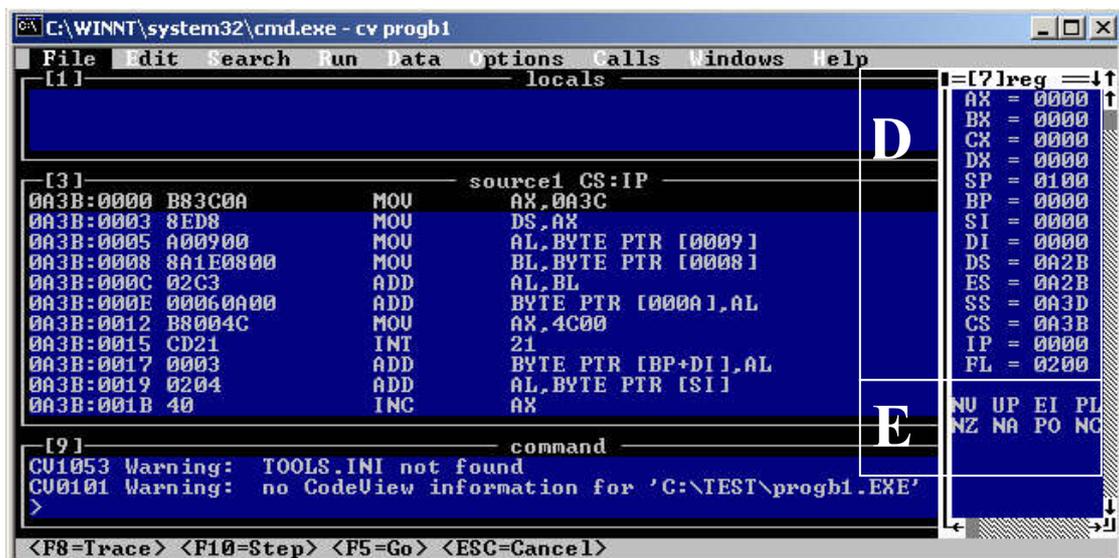


Fig 5: CV with Registers Window

## D: Registers

This part shows the current values of the registers, there are 14 registers shown. The default view is 16-bit registers for the 8086. You can view the 32-bit registers by going to the **Options** menu and selecting **32-bit Registers**.

Consider the first instruction. It moves the value “0A3C” into the register AX. Try to execute this instruction as you have learned. After executing this instruction, the value of AX will change to “0A3C” instead of “0000”. You can notice that any value that changes is highlighted.

After executing the previous instruction, notice that besides AX, another registers also have been highlighted, namely IP and FL. What do you think the cause for this?

<b>Overflow</b> NV: no overflow OV: overflow	<b>Direction</b> UP: up DN: down	<b>Interrupt</b> EI: Enable interrupt DI: Disable Interrupts	<b>Sign</b> NG: Negative PL: positive
<b>Zero</b> ZR: Zero NZ: No zero	<b>Auxiliary</b> AC: Auxiliary carry NA: No Auxiliary carry	<b>Parity</b> PE: Parity even PO: Parity odd	<b>Carry</b> CY: Carry NC: No carry

Fig 6: Flags and Their Values

## E: Flags

The lower part of the window contains the flags that indicate the status of the CPU after executing the last instruction. They are arranged as shown in Fig 6.

## Viewing the Data Segment Window

To view the *data segment* (DS) windows, press Alt+5. The following screen will appear.

```

C:\WINNT\system32\cmd.exe - cv progbl
File Edit Search Run Data Options Calls Windows Help
[1] locals
[3] source1 CS:IP
0A3B:0000 B83C0A MOU AX,0A3C
0A3B:0003 8ED8 MOU DS,AX
0A3B:0005 A00900 MOU AL,BYTE PTR [0009]
0A3B:0008 8A1E0800 MOU BL,BYTE PTR [0008]
0A3B:000C 02C3 ADD AL,BL
0A3B:000E 00060A00 ADD BYTE PTR [000A],AL
0A3B:0012 B8004C MOU AX,4C00
0A3B:0015 CD21 INT 21
0A3B:0017 0003 ADD BYTE PTR [BP+DI],AL
0A3B:0019 0204 ADD AL,BYTE PTR [SI]
0A3B:001B 40 INC AX
[7] reg
AX = 0000
BX = 0000
CX = 0000
DX = 0000
SP = 0100
BP = 0000
SI = 0000
DI = 0000
DS = 0A2B
ES = 0A2B
SS = 0A3D
CS = 0A3B
IP = 0000
FL = 0200
NU UP EI PL
NZ NA PO NC
[5] memory1 b DS:0
0A2B:0000 CD 20 FF 9F 00 9A F0 FE 1D F0 96 02 10 = f.U=I+u
0A2B:000D 08 97 03 10 08 56 01 15 04 D0 09 01 01
<F8=Trace> <F10=Step> <F5=Go> <F3=S1 Fmt> <Sh+F3=M1 Fmt> DEC

```

Fig 7: CV with Data Segment Windows

Notice that in Fig 7, each line contains 13 bytes. The address given at the beginning of the line is **Data Segment Address: Offset** of the first byte. This is why the next line starts from 000DH.

Be careful to one important point here. At the beginning of the program, the DS register was loaded with the value “0A3C”, which means that the data of our program is in the segment 0A3C. In the data segment register (DS) however, the segment shown initially is “0A2B” which is a different segment. To show the correct segment, put the cursor on the segment value in the data segment window and write the new value (0A3C). The new screen will look like Fig 8.

Now, let us see how to locate the values of the variables. Notice that the variable B has been replaced by BYTE PTR [0009]. This means that the offset of the address of B is 0009 inside the data segment. If you try to located the value B in the data segment as 0A3C:0009, you will find it 02.

As an exercise, try to find the values of A & C.

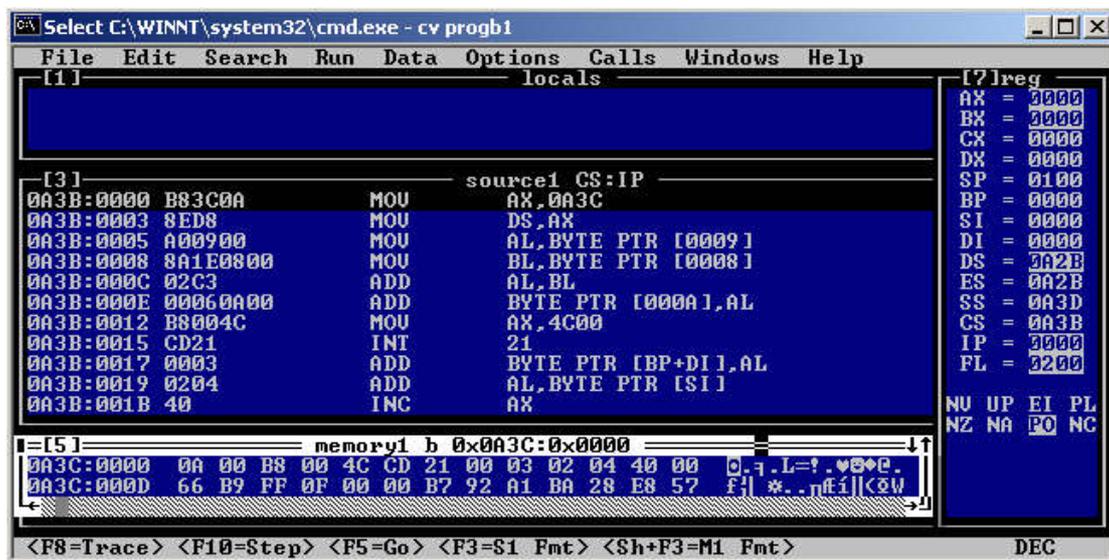


Fig 8: Data Segment with Correct Value.

**Student Name:**

**ID#**

## **Exercises**

1. You can view your system information by going to

**Start> Programs> Accessories> System Tools> System Information**

**Or**

Right click the **My Computer** icon on you desktop and select **Properties**

Use this tool to fill the following table.

<b>Processor</b>	
<b>Processor Speed</b>	(MHz/GHz)
<b>Memory Size</b>	MB
<b>Operating System</b>	

Now, use the information you collected to answer the following questions.

- a- Calculate the duration of one clock of your PC.

- b- What is the size of the **data bus** and the **address bus**?

**Data Bus:**

**Address Bus:**

- c- What is the maximum amount of data that can be transferred on the data bus in one cycle?

- d- What is the maximum amount of memory that your PC can address?

**Student Name:**

**ID#**

2. Write the following program and use the CV to answer the following questions?

```
TITLE "programB2"
.MODEL SMALL
.STACK 100
.DATA
    NUM1 DB 9
    NUM2 DB 8
    X     DB 'A'
.CODE
    MOV  AX,@DATA      ; 1
    MOV  DS,AX         ; 2

    MOV  AL,NUM1       ; 3
    ADD  NUM2,AL        ; 4
    MOV  BL,X          ; 5

    MOV  AX,4C00H      ; 6
    INT  21H           ; 7
END
```

- a- What is the **starting address** of the memory where the code of this program is stored?
- b- What is the **starting address** of the **data segment**?
- c- What is the equivalent **binary** code for the instruction#3? What is its size?
- d- How much **memory** is required to store the program?

**Student Name:**

**ID#**

e- By looking at the binary code, what type of instruction do you think the opcode "B8" refers to?

f- What is the **address** of the location storing the variables NUM1 & NUM2?

g- What is the value stored in the memory location of NUM2 before and after executing instruction#4?

**Before:**

**After:**

h- Write the status of the flags and their meanings after executing instruction#4?

<b>Overflow</b>	<b>Direction</b>	<b>Interrupt</b>	<b>Sign</b>
<b>Zero</b>	<b>Auxiliary</b>	<b>Parity</b>	<b>Carry</b>

i- Run the program step-by-step and write the values of the *source* and *destination* before and after each instruction.

<b>Instruction</b>	<b>Source</b>		<b>Destination</b>	
	<b>Before</b>	<b>After</b>	<b>Before</b>	<b>After</b>
MOV AX,@DATA				
MOV DS,AX				
MOV AL,NUM1				
ADD NUM2,AL				
MOV BL,C				
MOV AX,4C00H				
INT 21H				