# Computer Organization and Assembly Language

Introduction

# What is the course about?

- This course is about looking at lower level details of how computers works.
- In order to do so, we will see computer organization and architecture.
- You will also learn assembly language for Intel 8088 processor.
- At this point you have taken a course on High level language (C++), so its good time to get started looking at
  - How processor (CPU) is organized?
  - How program is executed on processor?
  - How processor interacts with memory and I/O devices?

# Books

- Assembly Language Programming Lecture Notes by Bilal Hashmi (BH).
- Assembly Language for x86 Processors Seventh Edition Kip R. Irvine (KI)
- Computer Organization and Architecture Designing for Performance Tenth Edition by William Stallings (WS)

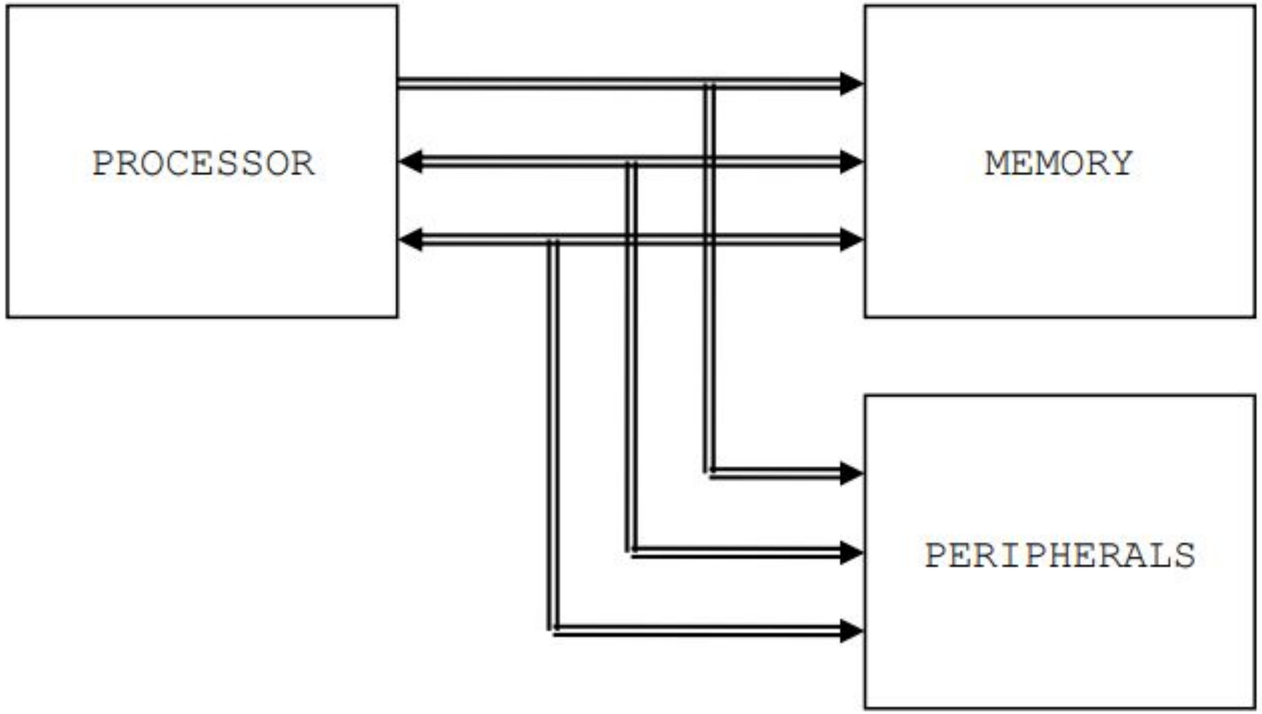
# Tentative Evaluation and Grading Policy

- You will be evaluated on quizzes, 2 mid term exams, 1 final exam and multiple assignments.
- Quizzes can be unannounced.
- Tentative Percentage Grade Distribution:

| | |
|---|---|
| QUIZZES | 10 |
| MIDTERMS | 30 |
| FINAL | 45 |
| ASSIGNMENTS | 15 |

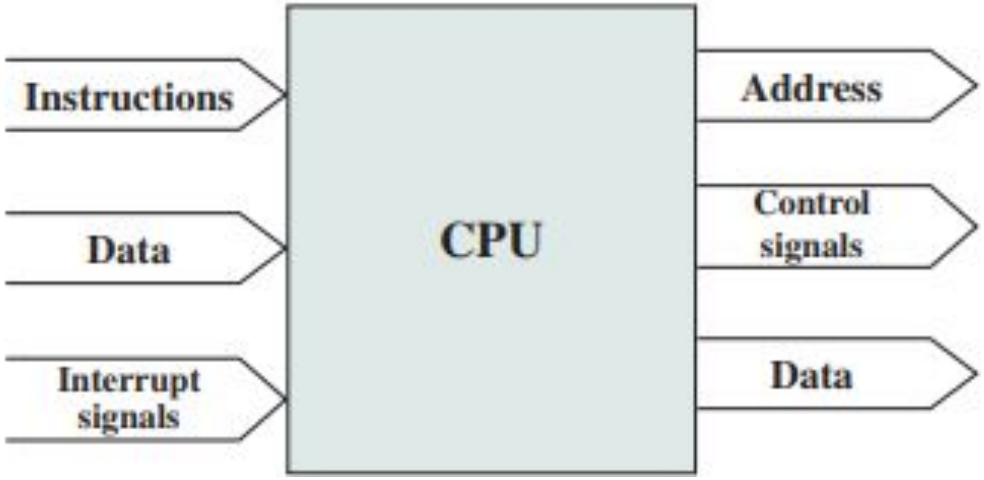
# Basic Components of Computer

- Section 1.1 BH



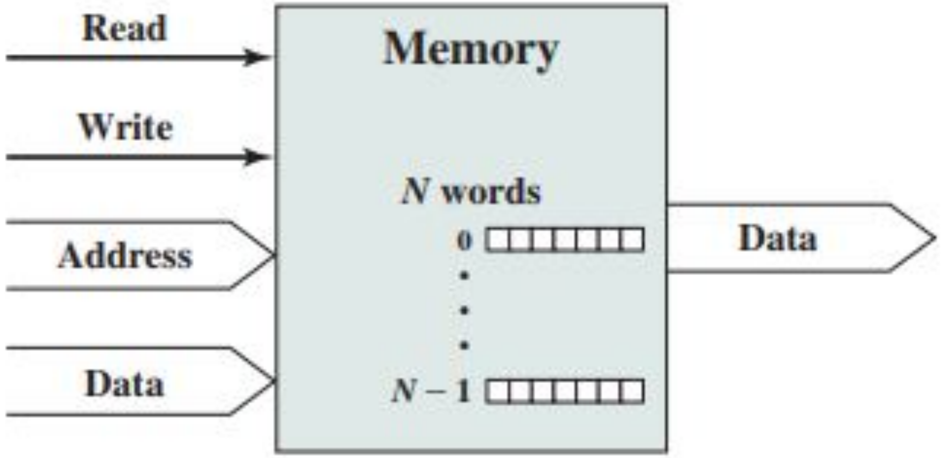
# Processor

- Processor: The processor reads in instructions and data, writes out data after processing, and uses control signals to control the overall operation of the system. It also receives interrupt signals



# Memory

- Memory: Typically, a memory module will consist of N words of equal length. Each word is assigned a unique numerical address (0, 1, c , N-1). A word of data can be read from or written into the memory. The nature of the operation is indicated by read and write control signals. The location for the operation is specified by an address.



# Buses

- A bus is a communication pathway connecting two or more devices. For example Processor to/from Memory, I/O to/from processor, I/O to/from Memory
- The group of bits that the processor uses to inform the memory about which element to read or write is collectively known as the address bus.
- Another important bus called the data bus is used to move the data from the memory to the processor in a read operation and from the processor to the memory in a write operation.
- The third group consists of miscellaneous independent lines used for control purposes. For example, one line of the bus is used to inform the memory about whether to do the read operation or the write operation. These lines are collectively known as the control bus

# A word about registers

- Registers are named storage locations in the CPU that hold intermediate results of operations.
- As they are located inside CPU they are fastest to access.
- Each processor has limited number of registers.

# How instructions are executed

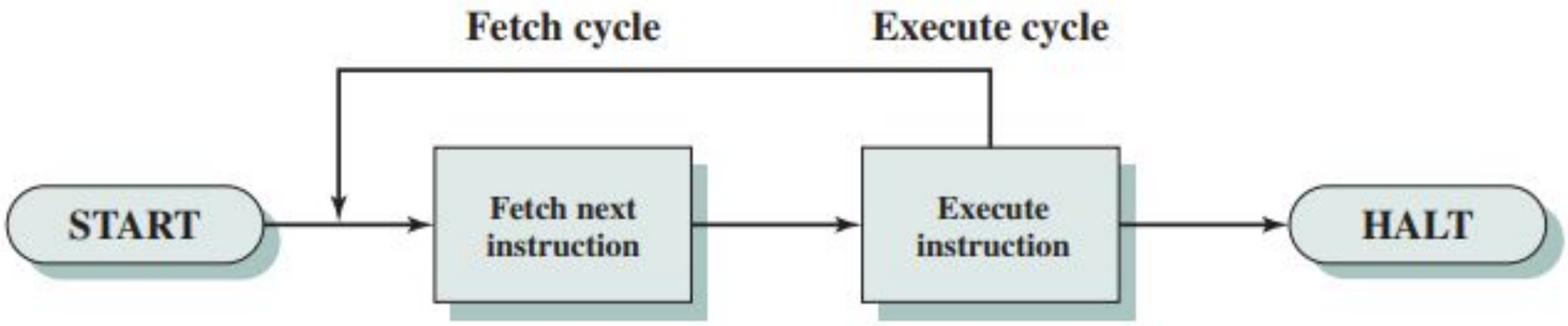



**Figure 3.3** Basic Instruction Cycle

# Assembly Language

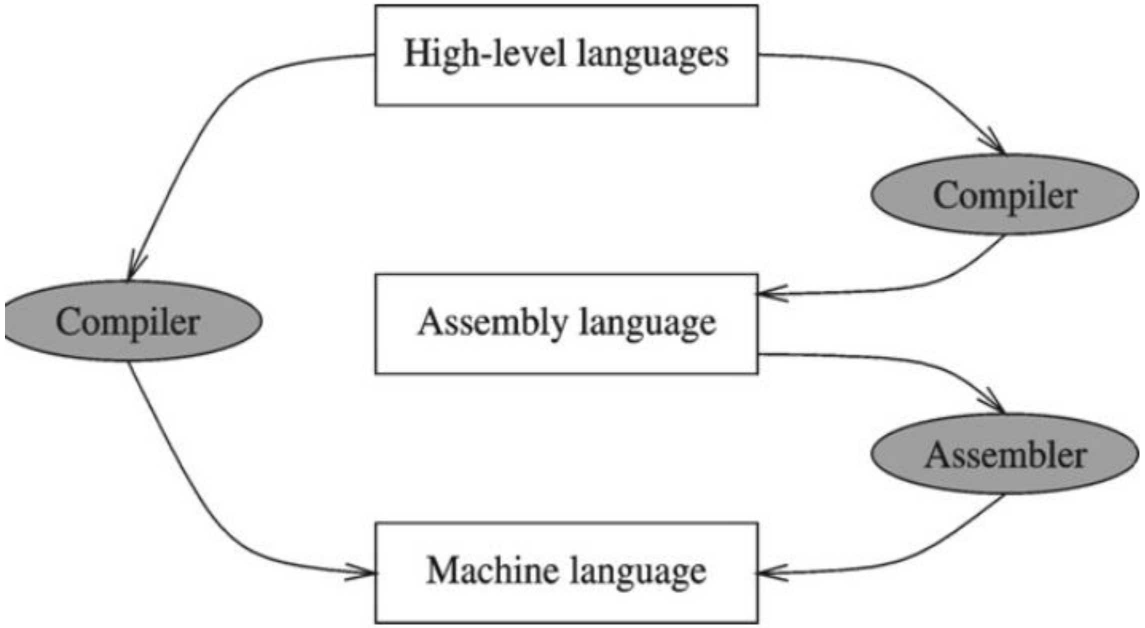
- Up till now the instruction you provided to your computer were in High level language, for example  code in C++.
- But processor doesn’t understand these high level languages. Its only understands 0 or 1. Called machine Language.
- Example of machine instruction to add two registers is

```
00000010 00110010 01000000 00100000
```

- Not very meaningful to us humans, image remembering a something like this for so many more instructions!!

# Compiler and Assembler

- Some compilers will first convert the code to assembly language and then to machine language (or object code)
- Some compilers will directly convert the code to  machine language (or object code)
- The object code generated is for particular type of processor.



# Why need Assembly language?

- To better understand the processor.
  - An assembly language program describes exactly what the hardware should do, step by step, in terms of the basic operations of the hardware. In a high level programming language like C or Java a programmer is mostly unaware of computer architecture.
  - This can also help in code optimization in terms of space and time.
- In some processors it might not be feasible to code in high level languages.

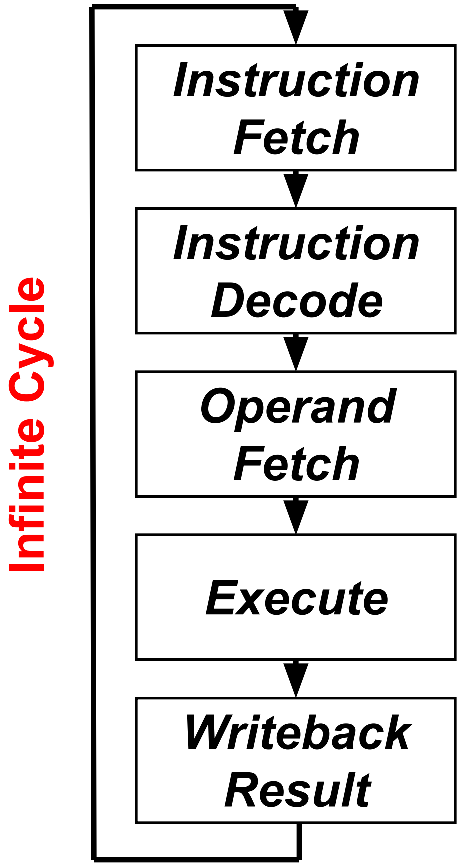
# Intel 8086 Processor

- There  is not just one language called "assembly language.“ Each processor family (such as Intel, VAX, MIPS, Alpha, ...) has its own architecture, organization and machine instructions and a corresponding assembly language.
- Learning about one processor and its assembly language is good enough to know how things work.
- In this course we will work with intel 8088 16 bit processor, which is a part of inter x86 family of processors.
- You will not work with the real processor but with

emulator ***DosBox***

- Other tools you will need are assembler and debugger

# Instruction Execute Cycle




Obtain instruction from program storage

Determine required actions and instruction size

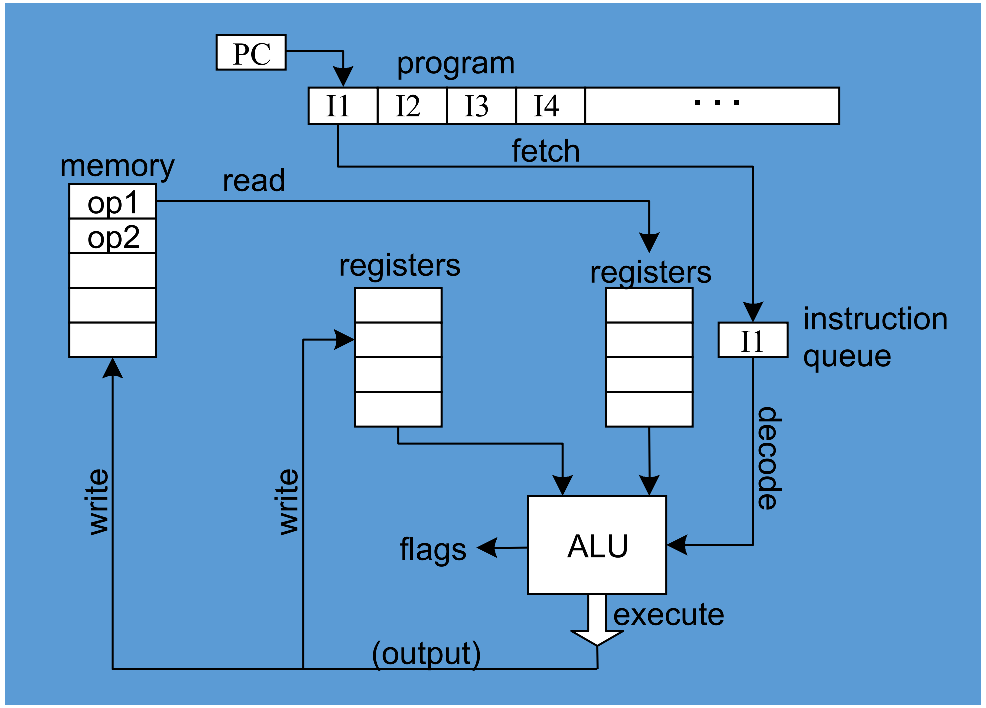
Locate and obtain operand data

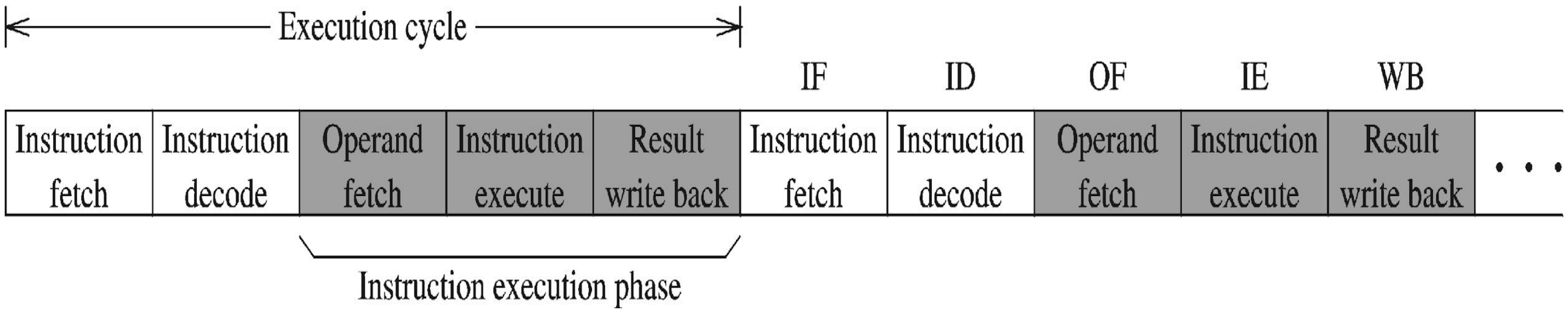
Compute result value and status

Deposit results in storage for later use

# Instruction Execution Cycle – cont'd

- Instruction Fetch
- Instruction Decode
- Operand Fetch
- Execute
- Result Write back



# Instruction Group

- Data Movement Instructions
  - These instructions are used to move data from one place to another.
  - These places can be registers, memory, or even inside peripheral devices. Some examples are:

```
mov ax, bx
lda 1234
```

- Arithmetic and Logic Instructions
  - Arithmetic instructions like addition, subtraction, multiplication, division and Logical instructions like logical and, logical or, logical xor, or complement are part of this group.
  - Some examples are:

```
and ax, 1234
add bx, 0534
add bx, [1200]
```

# Instruction Group

- Program Control Instructions
  - These are instructions that control the program execution and flow by playing with the instruction pointer and altering its normal behavior to point to the next instruction.
  - Some examples are:

```
cmp ax, 0
jne 1234
```

- Special Instructions
  - Another group called special instructions works like the special service commandos. They allow changing specific processor behaviors and are used to play with it. They are used rarely but are certainly used in any meaningful program. Some examples are:

```
cli
sti
```

  - Where cli clears the interrupt flag and sti sets it

# BASIC OPERAND TYPES

- Registers
  - Uses a named register in the CPU
  - Example

```
mov si,cx
add ax,bx
```

- Immediate operands
  - Constant expressions such as number , character constants or symbols are immediate operands, for example

```
mov ax,10
add ax,5
```

# BASIC OPERAND TYPES

- Direct operands
  - Refers to the content of memory at a location identified by a label in data segment, for example

```
mov ax, [num1]
num1:     dw 5
```

- Direct offset operand
  - Refers to the content of memory at a location identified by a label in data segment by +/- a value from offset, for example

```
mov ax, [num1+1]
num1:     dw 5
          dw 10
```

*Note that declaring data will be covered in coming lectures

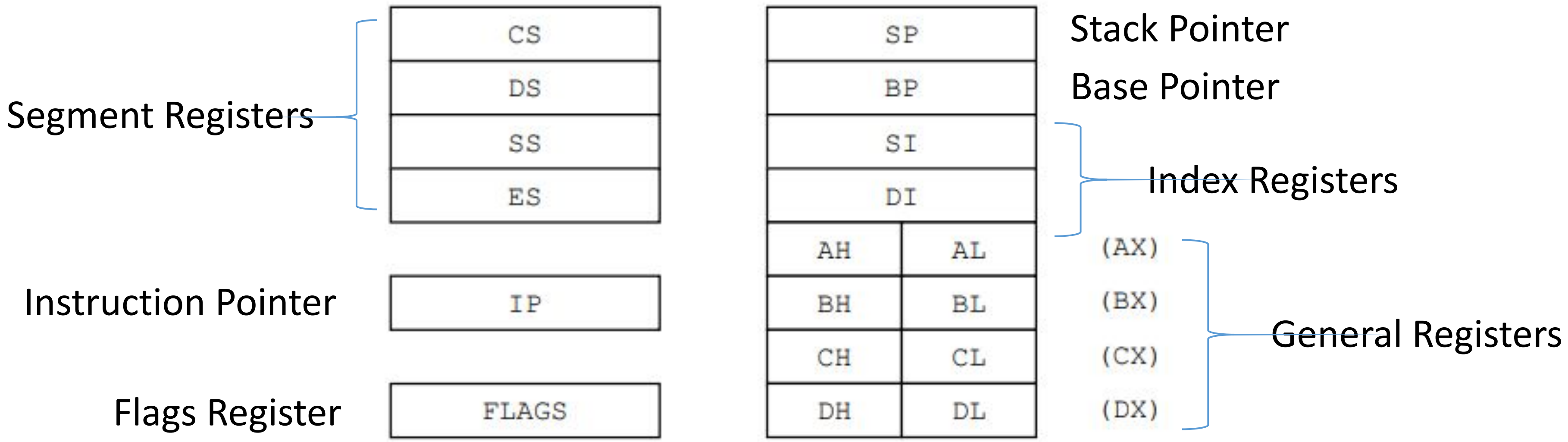
# INTEL IAPX88 ARCHITECTURE

# Registers

- Types of Registers
  - Accumulator
    - Central register in every processor
    - Traditionally all mathematical and logical operations are performed on the accumulator
    - n bit processor has n bit accumulator. For example a 16 bit processor has 16 bit accumulator.
  - Pointer, Index, or Base Register
    - Holds the address of data
  - Flag Register
    - This is a special register in every architecture called the flags register or the program status word.
    - The bits of the flags register work independently and individually, and combined its value is meaningless.
    - An example of a bit commonly present in the flags register is the carry flag
    - If a 16bit number is added to a 16bit accumulator, and the result is of 17 bits the 17th bit is placed in the carry bit of the flags register.
  - Program Counter or Instruction Pointer
    - The program counter holds the address of the next instruction to be executed

# IAPX88 REGISTER ARCHITECTURE

- 8088 is a 16bit processor with its accumulator and all registers of 16 bits
- Consists of 14 registers.



# General Registers (AX, BX, CX, and DX)

- Used for arithmetic and data movement
- X in their names stand for extended meaning 16bit registers
  - For example AX means we are referring to the extended 16bit “A” register
- Upper and lower half can be accessed separately,
  - For example
    - AH is for upper 8 bits (A high byte)
    - AL for lower 8 bits (A low byte)
    - AX is used to access whole 16 bits
  - Any changes in AH or AL are reflected in AX.

| | | |
|---|---|---|
| AH | AL | (AX) |
| BH | BL | (BX) |
| CH | CL | (CX) |
| DH | DL | (DX) |

# General Registers (AX, BX, CX, and DX)

- AX, A for accumulator, is the accumulator register as it is favored by CPU for arithmetic operations. Provides slightly more efficiency.
- BX, B for base, register can hold the address or procedure or variable. BS can also perform arithmetic or data movement.
- CX, C for counter, acts as counter for repeating or loop instructions. These instructions automatically repeat and decrement CX.
- DX (D for data), has special role in multiply and divide operations, When multiplying, for example, DX holds the high 16 bits of the product.

# Index Registers (SI and DI)

- SI and DI stand for source index and destination index respectively
- Hold address of data and used in memory access.
- For flexibility, Intel allows many mathematical and logical operations on these registers as well like the general registers.
- The source and destination are named because of their implied functionality as the source or the destination in a special class of instructions called the string instructions.
- SI and DI are 16bit and cannot be used as 8bit register pairs like AX, BX, CX, and DX.

# Instruction Pointer (IP)

- This is the special register containing the address of the next instruction to be executed.
- No mathematics or memory access can be done through this register.
- It is out of our direct control and is automatically used.
- Playing with it is dangerous and needs special care.
- Program control instructions change the IP register

# Stack Pointer (SP) and Base Pointer (BP)

- Stack Pointer (SP) is a memory pointer and is used indirectly by a set of instructions. This register will be explored in the discussion of the system stack.
- Base Pointer (BP) It is also a memory pointer containing the address in a special area of memory called the stack and will be explored alongside SP in the discussion of the stack

# Flags Register

- The flags register as previously discussed is not meaningful as a unit rather it is bit wise significant and accordingly each bit is named separately. The bits not named are unused. The Intel FLAGS register has its bits organized as follows:

| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | O | D | I | T | S | Z | | A | | P | | C |

- The individual flags are explained in the next table.
- Empty positions in figure are undefined.

| | | |
|---|---|---|
| C | Carry | When two 16bit numbers are added the answer can be 17 bits long or when two 8bit numbers are added the answer can be 9 bits long. This extra bit that won't fit in the target register is placed in the carry flag where it can be used and tested. |
| P | Parity | Parity is the number of "one" bits in a binary number. Parity is either odd or even. This information is normally used in communications to verify the integrity of data sent from the sender to the receiver. |
| A | Auxiliary Carry | A number in base 16 is called a hex number and can be represented by 4 bits. The collection of 4 bits is called a nibble. During addition or subtraction if a carry goes from one nibble to the next this flag is set. Carry flag is for the carry from the whole addition while auxiliary carry is the carry from the first nibble to the second. |
| Z | Zero Flag | The Zero flag is set if the last mathematical or logical instruction has produced a zero in its destination. |

| | | |
|---|---|---|
| S | Sign Flag | A signed number is represented in its two's complement form in the computer. The most significant bit (MSB) of a negative number in this representation is 1 and for a positive number it is zero. The sign bit of the last mathematical or logical operation's destination is copied into the sign flag. |
| T | Trap Flag | The trap flag has a special role in debugging which will be discussed later. |
| I | Interrupt Flag | It tells whether the processor can be interrupted from outside or not. Sometimes the programmer doesn't want a particular task to be interrupted so the Interrupt flag can be zeroed for this time. The programmer rather than the processor sets this flag since the programmer knows when interruption is okay and when it is not. Interruption can be disabled or enabled by making this bit zero or one, respectively, using special instructions. |
| D | Direction Flag | Specifically related to string instructions, this flag tells whether the current operation has to be done from bottom to top of the block (D=0) or from top to bottom of the block (D=1). |
| O | Overflow Flag | The overflow flag is set during signed arithmetic, e.g. addition or subtraction, when the sign of the destination changes unexpectedly. The actual process sets the overflow flag whenever the carry into the MSB is different from the carry out of the MSB |

# Segment Registers (CS, DS, SS, and ES)

- The code segment register, data segment register, stack segment register, and the extra segment register are special registers related to the Intel segmented memory model and will be discussed later.

# Bus and Memory

- 8088 has 8-bit data bus
- It has 20 bit address bus
- It can access 1MB of memory with this 20 bit address bus
  - $2^{20}$ = 1MB

# First Program in Assembly language

- The first program that we will write will only add three numbers.
- The addition operation is performed on data present in registers.
- As addition requires two operands, both the operands should be present in registers (or at least one)
- The next slide shows the code with comments.

**Example 1.1**

```
001  ; a program to add three numbers using registers
002  [org 0x0100]
003              mov   ax, 5            ; load first number in ax
004              mov   bx, 10           ; load second number in bx
005              add   ax, bx           ; accumulate sum in ax
006              mov   bx, 15           ; load third number in bx
007              add   ax, bx           ; accumulate sum in ax
008
009              mov   ax, 0x4c00       ; terminate program
010              int   0x21
```

- Things to note:
  - Abbreviations, for example move is written as mov in assembly operation
  - Code will always start with Line 2 and
  - Code will always ends with Line 9 and 10 to terminate program safely.
  - Instructions are written in following format
    - operation destination, source
  - Code is very much like English language for example
    - mov ax,5 means move 5 to ax

# Assemble line and Debug code

- NASM (Netwide Assembler)will be used to assemble the code and create executable file with .com extension
- AFD (A fullscreen debugger) will be used to debug the code.
- DOSBox will be used to emulate 8088 processor.
- Installation of these tools will be discussed in lab.
- Save the code given in previous slide with .asm extension.
- Following command will be used to assemble the code

```
nasm ex01.asm –o ex01.com –l ex01.lst
```

# Listing File

- The listing file created has a lot of information. And is annotated as follow

Offset of instruction in hex

OPCODE in hex and Operand in little-endian hex

Assemble code

```
 1
 2                                          [org 0x0100]
 3 00000000 B80500                            mov   ax, 5
 4 00000003 BB0A00                            mov   bx, 10
 5 00000006 01D8                              add   ax, bx
 6 00000008 BB0F00                            mov   bx, 15
 7 0000000B 01D8                              add   ax, bx
 8
 9 0000000D B8004C                            mov   ax, 0x4c00
10 00000010 CD21                              int   0x21
```

Size of last instruction (line 10) is 2 bytes so total size of .com file is 16+2=18bytes

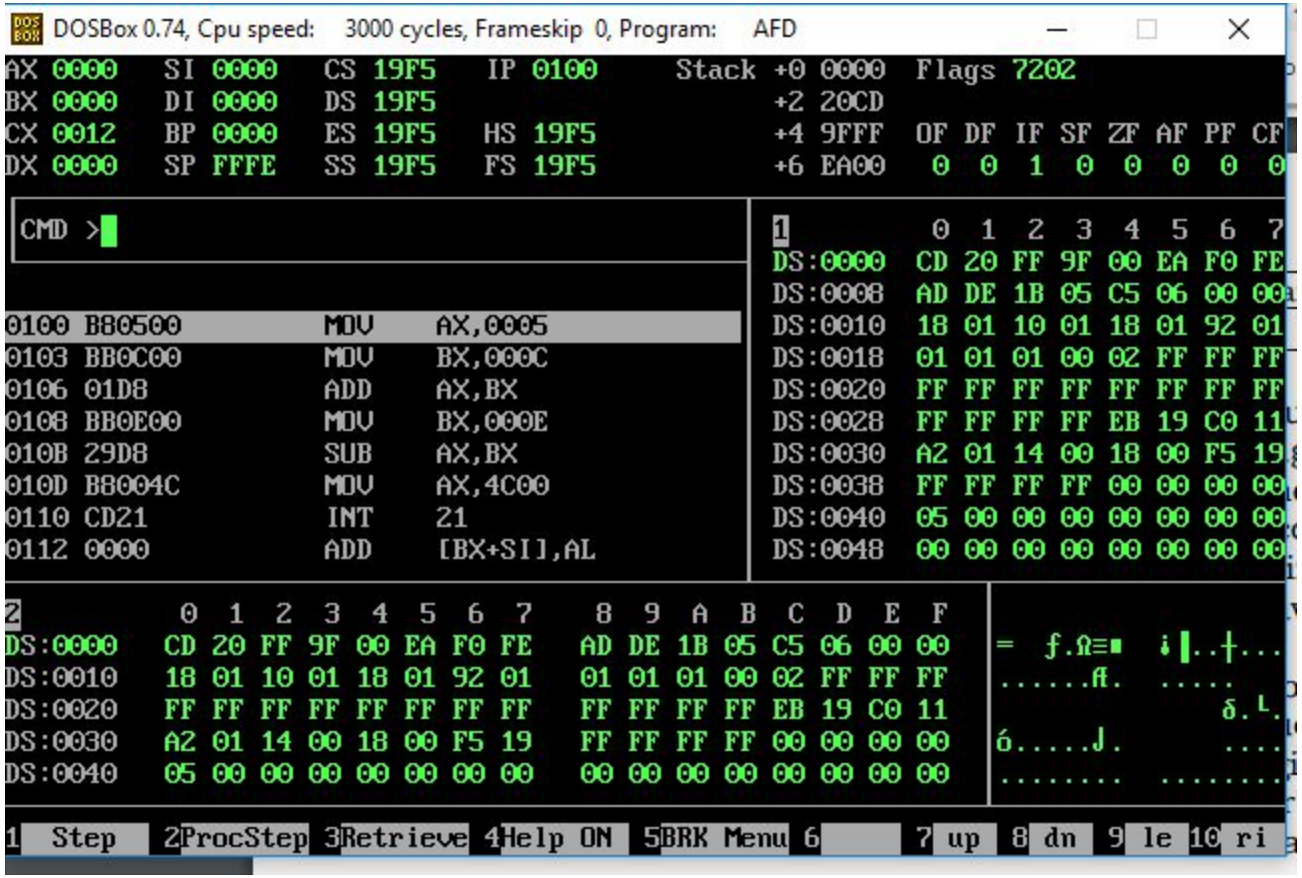
# Debug

- Following command will be used to debug the file

```
afd ex01.com
```

- The debugger shows the values of registers, flags, stack, our code, and one or two areas of the system memory as data.
- Debugger allows us to step our program one instruction at a time and observe its effect on the registers and program data.

- Things to note:
  - Registers
  - Memory (m1 and m2 view)
  - Offset of 1st instruction
  - IP
  - Hit F1 to execute instruction
  - See the change in registers/memory



# References


- https://sites.google.com/view/coal-fall-2019