8086 Assembly Language Programming

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Outline

- **Why Assembly Language Programming**
- **Organization of 8086 processor**
- **Assembly Language Syntax**
- **Data Representation**
- **Variable Declaration**
- **Instruction Types**
  - Data flow instructions
  - Arithmetic instructions
  - Bit manipulation instructions
  - Flow control instructions
- **Memory Segmentation**

Outline – Cont.

- **Program Structure**
- **Addressing Modes**
- **Input and Output**
- **The stack**
- **Procedures**
- **Macros**
- **String Instructions**
- **BIOS and DOS Interrupts**

Machine/Assembly Language

- **Machine Language:**
  - Set of fundamental instructions the machine can execute
  - Expressed as a pattern of 1's and 0's
- **Assembly Language:**
  - Alphanumeric equivalent of machine language
  - Mnemonics more human-oriented than 1's and 0's
- **Assembler:**
  - Computer program that transliterates (one-to-one mapping) assembly to machine language
  - Computer's native language is machine/assembly language

Why Assembly Language Programming

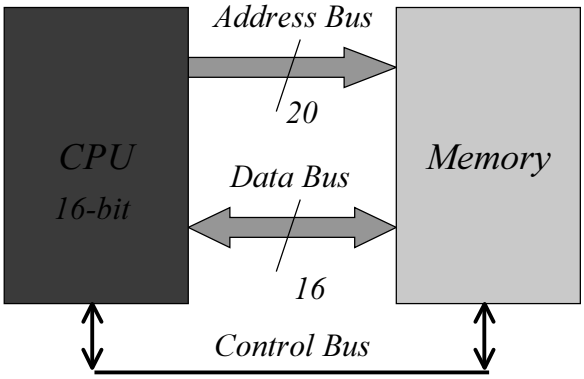
- **Faster and shorter programs.**
  - Compilers do not always generate optimum code.
- **Instruction set knowledge is important for machine designers.**
- **Compiler writers must be familiar with details of machine language.**
- **Small controllers embedded in many products**
  - Have specialized functions,
  - Rely so heavily on input/output functionality,
  - HLLs inappropriate for product development.

Programmer's Model: Instruction Set Architecture

- **Instruction set: collection of all machine operations.**
- **Programmer sees set of instructions, and machine resources manipulated by them.**
- **ISA includes**
  - Instruction set,
  - Memory, and
  - Programmer-accessible registers.
- **Temporary or scratch-pad memory used to implement some functions is not part of ISA**
  - Not programmer accessible.

Organization of 8086 Processor

CPU-Memory Interface



CPU Registers

- **Fourteen 16-bit registers**
- **Data Registers**
  - AX (Accumulator Register): AH and AL
  - BX (Base Register): BH and BL
  - CX (Count Register): CH and CL
  - DX (Data Register): DH and DL
- **Pointer and Index Registers**
  - SI (Source Index)
  - DI (Destination Index)
  - SP (Stack Pointer)
  - BP (Base Pointer)
  - IP (Instruction Pointer)

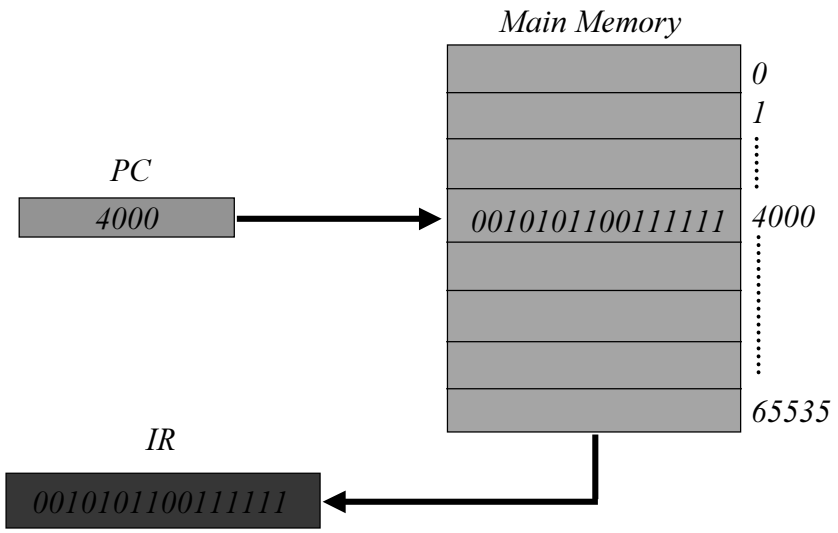
CPU Registers – Cont.

- **Segment Registers**
  - CS (Code Segment)
  - DS (Data Segment)
  - SS (Stack Segment)
  - ES (Extra Segment)
- **FLAGS Register**
  - Zero flag
  - Sign flag
  - Parity flag
  - Carry flag
  - Overflow flag

Fetch-Execute Process

- **Program Counter (PC) or Instruction Pointer (IP)**
  - Holds address of next instruction to fetch
- **Instruction Register (IR)**
  - Stores the instruction fetched from memory
- **Fetch-Execute process**
  - Read an instruction from memory addressed by PC
  - Increment program counter
  - Execute fetched instruction in IR
  - Repeat process

Fetch-Execute Process – Cont.



Assembly Language Syntax

- **Program consists of statement per line.**
- **Each statement is an instruction or assembler directive**
- **Statement syntax**
  - Name operation operand(s) comment
- **Name field**
  - Used for instruction labels, procedure names, and variable names.
  - Assembler translates names into memory addresses
  - Names are 1-31 characters including letters, numbers and special characters ? . @ _ $ %
  - Names may not begin with a digit
  - If a period is used, it must be first character
  - Case insensitive

Assembly Language Syntax – Cont.

- **Examples of legal names**
  - COUNTER1
  - @character
  - SUM_OF_DIGITS
  - $1000
  - Done?
  - .TEST
- **Examples of illegal names**
  - TWO WORDS
  - 2abc
  - A45.28
  - You&Me

Assembly Language Syntax – Cont.

- **Operation field**
  - instruction
    - Symbolic operation code (opcode)
    - Symbolic opcodes translated into machine language opcode
    - Describes operation's function; e.g. MOV, ADD, SUB, INC.
  - Assembler directive
    - Contains pseudo-operation code (pseudo-op)
    - Not translated into machine code
    - Tell the assembler to do something.
- **Operand field**
  - Specifies data to be acted on
  - Zero, one, or two operands
    - NOP
    - INC AX
    - ADD AX, 2

Assembly Language Syntax – Cont.

- **Comment field**
  - A semicolon marks the beginning of a comment
  - A semicolon in beginning of a line makes it all a comment line
  - Good programming practice dictates comment on every line
- **Examples**
  - MOV CX, 0 ; move 0 to CX
    - Do not say something obvious
  - MOV CX, 0 ; CX counts terms, initially 0
    - Put instruction in context of program
  - ; initialize registers

Data Representation

- **Numbers**
  - 11011 decimal
  - 11011B binary
  - 64223 decimal
  - -21843D decimal
  - 1,234 illegal, contains a nondigit character
  - 1B4DH hexadecimal number
  - 1B4D illegal hex number, does not end with “H”
  - FFFFH illegal hex numbe, does not begin with with digit
  - 0FFFFH hexadecimal number
- **Signed numbers represented using 2’s complement.**

Data Representation - Cont.

- **Characters**
  - must be enclosed in single or double quotes
  - e.g. “Hello”, ‘Hello’, “A”, ‘B’
  - encoded by ASCII code
- **‘A’ has ASCII code 41H**
- **‘a’ has ASCII code 61H**
- **‘0’ has ASCII code 30H**
- **Line feed has ASCII code 0AH**
- **Carriage Return has ASCII code 0DH**
- **Back Space has ASCII code 08H**
- **Horizontal tab has ASCII code 09H**

Data Representation - Cont.

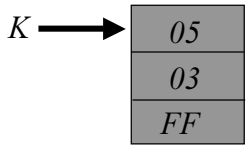
- **The value of the content of registers or memory is dependent on the programmer.**
- **Let AL=FFH**
  - represents the unsigned number 255
  - represents the signed number -1 (in 2’s complement)
- **Let AH=30H**
  - represents the decimal number 48
  - represents the character ‘0’
- **Let BL=80H**
  - represents the unsigned number +128
  - represents the signed number -128

Variable Declaration

- **Each variable has a type and assigned a memory address.**
- **Data-defining pseudo-ops**
  - DB define byte
  - DW define word
  - DD define double word (two consecutive words)
  - DQ define quad word (four consecutive words)
  - DT define ten bytes (five consecutive words)
- **Each pseudo-op can be used to define one or more data items of given type.**

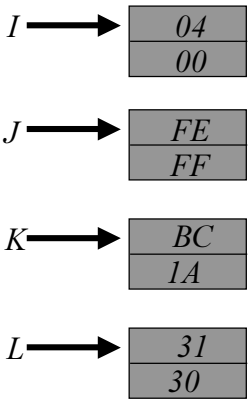
Byte Variables

- **Assembler directive format defining a byte variable**
  - name DB initial value
  - a question mark (“?”) place in initial value leaves variable uninitialized
- **I DB 4 define variable I with initial value 4**
- **J DB ? Define variable J with uninitialized value**
- **Name DB “Course” allocate 6 bytes for Name**
- **K DB 5, 3, -1 allocates 3 bytes**



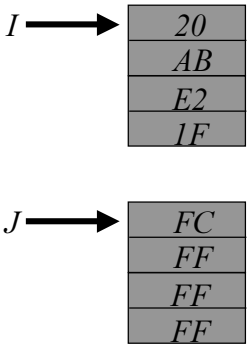
Word Variables

- **Assembler directive format defining a word variable**
  - name DW initial value
- **I DW 4**
- **J DW -2**
- **K DW 1ABCH**
- **L DW "01"**



Double Word Variables

- **Assembler directive format defining a word variable**
  - name DD initial value
- **I DD 1FE2AB20H**
- **J DD -4**



Named Constants

- **EQU pseudo-op used to assign a name to constant.**
- **Makes assembly language easier to understand.**
- **No memory allocated for EQU names.**
- **LF EQU 0AH**
  - MOV DL, 0AH
  - MOV DL, LF
- **PROMPT EQU "Type your name"**
  - MSG DB "Type your name"
  - MDG DB PROMPT

DUP Operator

- **Used to define arrays whose elements share common initial value.**
- **It has the form: repeat_count DUP (value)**
- **Numbers DB 100 DUP(0)**
  - Allocates an array of 100 bytes, each initialized to 0.
- **Names DW 200 DUP(?)**
  - Allocates an array of 200 uninitialized words.
- **Two equivalent definitions**
  - Line DB 5, 4, 3 DUP(2, 3 DUP(0), 1)
  - Line DB 5, 4, 2, 0, 0, 0, 1, 2, 0, 0, 0, 1, 2, 0, 0, 0, 1

Instruction Types

- **Data transfer instructions**
  - Transfer information between registers and memory locations or I/O ports.
  - MOV, XCHG, LEA, PUSH, POP, PUSHF, POPF, IN, OUT.
- **Arithmetic instructions**
  - Perform arithmetic operations on binary or binary-coded-decimal (BCD) numbers.
  - ADD, SUB, INC, DEC, ADC, SBB, NEG, CMP, MUL, IMUL, DIV, IDIV, CBW, CWD.
- **Bit manipulation instructions**
  - Perform shift, rotate, and logical operations on memory locations and registers.
  - SHL, SHR, SAR, ROL, ROR, RCL, RCR, NOT, AND, OR, XOR, TEST.

Instruction Types – Cont.

- **Control transfer instructions**
  - Control sequence of program execution; include jumps and procedure transfers.
  - JMP, JG, JL, JE, JNE, JGE, JLE, JNG, JNL, JC, JS, JA, JB, JAE, JBE, JNB, JNA, JO, JZ, JNZ, JP, JCXZ, LOOP, LOOPE, LOOPZ, LOOPNE, LOOPNZ, CALL, RET.
- **String instructions**
  - Move, compare, and scan strings of information.
  - MOVS, MOVSB, MOVSW, CMPS, CMPSB, CMPSW. SCAS, SCASB, SCASW, LODS, LODSB, LODSW, STOS, STOSB, STOSW.

Instruction Types – Cont.

- **Interrupt instructions**
  - Interrupt processor to service specific condition.
  - INT, INTO, IRET.
- **Processor control instructions**
  - Set and clear status flags, and change the processor execution state.
  - STC, STD, STI.
- **Miscellaneous instructions**
  - NOP, WAIT.

General Rules

- **Both operands have to be of the same size.**
  - MOV AX, BL illegal
  - MOV AL, BL legal
  - MOV AH, BL legal
- **Both operands cannot be memory operands simultaneously.**
  - MOV i, j illegal
  - MOV AL, i legal
- **First operand cannot be an immediate value.**
  - ADD 2, AX illegal
  - ADD AX, 2 legal

Memory Segmentation

- **A memory segment is a block of 2^{16} (64K) bytes.**
- **Each segment is identified by a segment number**
  - Segment number is 16 bits (0000 - FFFF).
- **A memory location is specified by an offset within a segment.**
- **Logical address: segment:offset**
  - A4FB:4872h means offset 4872h within segment A4FBh.
- **Physical address: segment * 10H + offset**
  - A4FB*10h + 4872 = A4FB0 + 4872 = A9822h (20-bit address)
- **Physical address maps to several logical addresses**
  - physical address 1256Ah=1256:000Ah=1240:016Ah

Memory Segmentation - Cont.

- **Location of segments**
  - Segment 0 starts at address 0000:0000=00000h and ends at 0000:FFFF=0FFFFh.
  - Segment 1 starts at address 0001:0000=00010h and ends at 0001:FFFF= 1000Fh.
  - Segments overlap.
  - The starting physical address of any segment has the first hex digit as 0.
- **Program segments**
  - Program's code, data, and stack are loaded into different memory segments, namely code segment, data segment and stack segment.
  - At any time, only four memory segments are active.
  - Program segment need not occupy entire 64K byte.

Memory Segmentation - Cont.

- **Data Segment**
  - contains variable definitions
  - declared by .DATA
- **Stack segment**
  - used to store the stack
  - declared by .STACK size
  - default stack size is 1Kbyte.
- **Code segment**
  - contains program's instructions
  - declared by .CODE

Memory Models

- **SMALL**
  - code in one segment & data in one segment
- **MEDIUM**
  - code in more than one segment & data in one segment
- **COMPACT**
  - code in one segment & data in more than one segment
- **LARGE**
  - code in more than one segment & data in more than one segment & no array larger than 64K bytes
- **HUGE**
  - code in more than one segment & data in more than one segment & arrays may be larger than 64K bytes

Program Structure: An Example

```
TITLE PRGM1
.MODEL SMALL
.STACK 100H
.DATA
        A       DW 2
        B       DW 5
        SUM DW ?
.CODE
MAIN PROC
; initialize DS
        MOV AX, @DATA
        MOV DS, AX
```


Program Structure: An Example

```
; add the numbers
        MOV AX, A
        ADD AX, B
        MOV SUM, AX
; exit to DOS
        MOV AX, 4C00H
        INT 21H
MAIN ENDP
        END MAIN
```

Assembling & Running A Program

- **Assembling a program**
  - Use microsoft macro assembler (MASM)
  - MASM PRGM1.ASM
    - Translates the assembly file PROG1.ASM into machine language object file PROG1.OBJ
    - Creates a listing file PROG1.LST containing assembly language code and corresponding machine code.
- **Linking a program**
  - The .OBJ file is a machine language file but cannot be run
    - Some addresses not filled since it is not known where a program will be loaded in memory.
    - Some names may not have been defined.
    - Combines one or more object files and creates a single executable file (.EXE).
    - LINK PROG1

Assembling & Running A Program

- **Running a program**
  - Type the name of the program to load it and run it
- **Simplified procedure**
  - Ml /Fl /Zi PROG1.ASM
  - Assembles and links the program
- **Debugging a program**
  - To analyze a program use CODE View debugger.
  - CV PROG1

Addressing Modes

- **Addressing mode is the way an operand is specified.**
- **Register mode**
  - operand is in a register
  - MOV AX, BX
- **Immediate mode**
  - operand is constant
  - MOV AX, 5
- **Direct mode**
  - operand is variable
  - MOV AL, i

Addressing Modes - Cont.

- **Register indirect mode**
  - offset address of operand is contained in a register.
  - Register acts as a pointer to memory location.
  - Only registers BX, SI, DI, or BP are allowed.
  - For BX, SI, DI, segment number is in DS.
  - For BP, segment number is in SS.
  - Operand format is [register]
- **Example: suppose SI=0100h and [0100h]=1234h**
  - MOV AX, SI AX=0100h
  - MOV AX, [SI] AX=1234h

Addressing Modes - Cont.

- **Based & Indexed addressing modes**
  - operand's offset address obtained by adding a displacement to the content of a register
- **Displacement may be:**
  - offset address of a variable
  - a constant (positive or negative)
  - offset address of a variable plus or minus a constant
- **Syntax of operand**
  - [register + displacement]
  - [displacement + register]
  - [register] + displacement
  - displacement + [register]
  - displacement [register]

Addressing Modes - Cont.

- **Based addressing mode**
  - If BX or BP used
- **Indexed addressing mode**
  - If SI or DI used
- **Examples:**
  - MOV AX, W [BX]
  - MOV AX, [W+BX]
  - MOV AX, [BX+W]
  - MOV AX, W+[BX]
  - MOV AX, [BX]+W
- **Illegal examples:**
  - MOV AX, [BX]2
  - MOV BX, [AX+1]

Addressing Modes - Cont.

- **Based-Indexed mode: offset address is the sum of**
  - contents of a base register (BX or BP)
  - contents of an index register (SI or DI)
  - optionally, a variable's offset address
  - optionally, a constant (positive or negative)
- **Operand may be written in several ways**
  - variable[base_register][index_register]
  - [base-register + index_register + variable + constant]
  - variable [base_register + index_register + constant]
  - constant [base_register + index_register + variable]
- **Useful for accessing two-dimensional arrays**

PTR Operator

- **Used to override declared type of an address expression.**
- **Examples:**
  - MOV [BX], 1 illegal, there is ambiguity
  - MOV Bye PTR [BX], 1 legal
  - MOV WORD PTR [BX], 1 legal
- **Let j be defined as follows**
  - j DW 10
  - MOV AL, j illegal
  - MOV AL, Byte PTR J legal

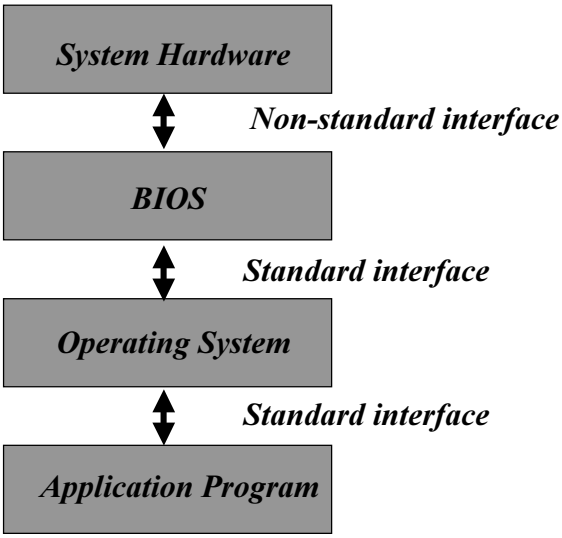
Input and Output

- **CPU communicates with peripherals through I/O registers called I/O ports.**
- **Two instructions access I/O ports directly: IN and OUT.**
  - Used when fast I/O is essential, e.g. games.
- **Most programs do not use IN/OUT instructions**
  - port addresses vary among computer models
  - much easier to program I/O with service routines provided by manufacturer
- **Two categories of I/O service routines**
  - Basic input/output system (BIOS) routines
  - Disk operating system (DOS) routines
- **DOS and BIOS routines invoked by INT (interrupt) instruction.**

System BIOS

- **A set of programs always present in system**
- **BIOS routines most primitive in a computer**
  - Talks directly to system hardware
  - Hardware specific - must know exact port address and control bit configuration for I/O devices
- **BIOS supplied by computer manufacturer and resides in ROM**
- **Provides services to O.S. or application**
- **Enables O.S. to be written to a standard interface**

Software Layers



Input/Output - Cont.

- **INT 21H used to invoke a large number of DOS function.**
- **Type of called function specified by putting a number in AH register.**
  - AH=1 single-key input with echo
  - AH=2 single-character output
  - AH=9 character string output
  - AH=8 single-key input without echo
  - AH=0Ah character string input

Single-Key Input

- **Input: AH=1**
- **Output: AL= ASCII code if character key is pressed, otherwise 0.**
- **To input character with echo:**
  - MOV AH, 1
  - INT 21H ; read character will be in AL register
- **To input a character without echo:**
  - MOV AH, 8
  - INT 21H ; read character will be in AL register

Single-Character Output

- **Input: AH=2, DL= ASCII code of character to be output**
- **Output: AL=ASCII code of character**
- **To display a character**
  - MOV AH, 2
  - MOV DL, '?' ; displaying character '?'
  - INT 21H
- **To read a character and display it**
  - MOV AH, 1
  - INT 21H
  - MOV AH, 2
  - MOV DL, AL
  - INT 21H

Displaying a String

- **Input: AH=9, DX= offset address of a string.**
- **String must end with a '$' character.**
- **To display the message Hello!**
  - MSG DB "Hello!$"
  - MOV AH, 9
  - MOV DX, offset MSG
  - INT 21H
- **OFFSET operator returns the address of a variable**
- **The instruction LEA (load effective address) loads destination with address of source**
  - LEA DX, MSG

Inputting a String

- **Input: AH=10, DX= offset address of a buffer to store read string.**
  - First byte of buffer should contain maximum string size+1
  - Second byte of buffer reserved for storing size of read string.
- **To read a Name of maximum size of 20 & display it**
  - Name DB 21,0,22 dup("$")
  - MOV AH, 10
  - LEA DX, Name
  - INT 21H
  - MOV AH, 9
  - LEA DX, Name+2
  - INT 21H

A Case Conversion Program

- **Prompt the user to enter a lowercase letter, and on next line displays another message with letter in uppercase.**
  - Enter a lowercase letter: a
  - In upper case it is: A
- **.DATA**
  - CR EQU 0DH
  - LF EQU 0AH
  - MSG1 DB 'Enter a lower case letter: $'
  - MSG2 DB CR, LF, 'In upper case it is: '
  - Char DB ?, '$'

A Case Conversion Program - Cont.

- **.CODE**
  - .STARTUP ; initialize data segment
  - LEA DX, MSG1 ; display first message
  - MOV AH, 9
  - INT 21H
  - MOV AH, 1 ; read character
  - INT 21H
  - SUB AL, 20H ; convert it to upper case
  - MOV CHAR, AL ; and store it
  - LEA DX, MSG2 ; display second message and
  - MOV AH, 9 ; uppercase letter
  - INT 21H
  - .EXIT ; return to DOS

Status & Flags Register

- **Carry flag (CF): CF=1 if there is**
  - a carry out from most significant bit (msb) on addition
  - a borrow into msb on subtraction
  - CF also affected differently by shift and rotate instructions
- **Parity flag (PF): PF=1 if**
  - low byte of result has an even number of one bits (even parity)

Status & Flags Register - Cont.

- **Auxiliary carry flag (AF): AF=1 if there is**
  - a carry out from bit 3 on addition
  - a borrow into bit 3 on subtraction
- **Zero flag (ZF): ZF=1**
  - if the result is zero
- **Sign flag (SF): SF=1 if**
  - msb of result is 1 indicating that the result is negative for signed number interpretation
- **Overflow flag (OF): OF=1**
  - if signed overflow occurs

How Processor Indicates Overflow

- **Unsigned overflow**
  - occurs when there is a carry out of msb
- **Signed overflow occurs**
  - on addition of numbers with same sign, when sum has a different sign.
  - on subtraction of numbers with different signs, when result has a different sign than first number.
  - If the carries into and out of msb are different.
- **Example:**

SF=1 PF=0 ZF=0 CF=1 OF=0

```
  FFFF
+ FFFF
------
1 FFFEh
```


MOV Instruction

- **Syntax: MOV destination, source**
  - Destination← source
- **Transfer data between**
  - Two registers
  - A register and a memory location
  - A constant to a register or memory location

	General Register	Segment Register	Memory Location	Constant
General Register	**yes**	**yes**	**yes**	**yes**
Segment Register	**yes**	**no**	**yes**	**no**
Memory Location	**yes**	**yes**	**no**	**yes**

MOV Instruction – Cont.

- **MOV instruction has no effect on flags.**
- **Examples:**
  - MOV DS, @Data illegal
  - MOV DS, ES illegal
  - MOV [BX], -1 illegal
  - MOV [DI], [SI] illegal
  - MOV AL, offset I illegal
  - MOV [BX], offset I illegal
  - MOV [SI], I illegal
  - MOV DS, [BX] legal
  - MOV AX, [SI] legal
  - MOV [BX-1], DS legal

XCHG Instruction

- **Syntax: XCHG operand1, operand2**
  - Operand1← operand2
  - Operand2← operand1
- **Exchanges contents of two registers, or a register and a memory location.**

	General Register	Memory Location
General Register	**yes**	**yes**
Memory Location	**yes**	**no**

- **XCHG has no effect on flags.**

ADD & SUB Instructions

- **Syntax:**
  - ADD destination, source ; destination=destination+ source
  - SUB destination, source ; destination=destination-source

	General Register	Memory Location	Constant
General Register	yes	yes	yes
Memory Location	yes	no	yes

- **ADD and SUB instructions affect all the flags.**

INC & DEC Instructions

- **Syntax:**
  - INC operand ; operand=operand+1
  - DEC operand ; operand=operand-1
- **Operand can be a general register or memory.**
- **INC and DEC instructions affect all the flags.**
- **Examples:**
  - INC AX legal
  - DEC BL legal
  - INC [BX] illegal
  - INC Byte PTR [BX] legal
  - DEC I legal
  - INC DS illegal

NEG instruction

- **Syntax: NEG operand**
  - Operand← 0 – operand
- **Finds the two's complement of operand.**
- **Operand can be a general register or memory location.**
- **NEG instruction affects all flags.**
- **Examples:**
  - Let AX=FFF0h and I=08h
  - NEG AX ; AX←0010
  - NEG AH ; AH←01
  - NEG I ; I←F8

CMP instruction

- **Syntax: CMP operand1, operand2**
  - Operand1-operand2
- **Subtracts operand2 from operand1 and updates the flags based on the result.**
- **CMP instruction affects all the flags.**

	General Register	Memory Location	Constant
General Register	yes	yes	yes
Memory Location	yes	no	yes

ADC and SBB instruction

- **Syntax:**
  - ADC destination, source ; destination=destination+source+CF
  - SBB destination, source ; destination=destination-source-CF
- **Achieve double-precision addition/subtraction.**
- **To add or subtract 32-bit numbers**
  - Add or subtract lower 16 bits
  - Add or subtract higher 16 bits with carry or borrow
- **Example: Add the two double words in A and B**
  - MOV AX, A
  - MOV DX, A+2
  - ADD B, AX
  - ADC B+2, DX

Multiplication

- **Unsigned multiplication: MUL operand**
- **Signed multiplication: IMUL operand**
- **If operand is a Byte**
  - MUL operand; AX← AL * operand
- **If operand is a Word**
  - MUL operand; DX:AX ← AX * operand
- **Operand can be a general register or memory. Cannot be a constant.**
- **Flags SF, ZF, AF, and PF are undefined.**
- **Only CF and OF are affected.**

Multiplication – Cont.

- **CF=OF=0**
  - Unsigned multiplication: if upper half of result is 0.
  - Signed multiplication: if upper half of result is a sign extension of lower half.
- **Example: Let AX=FFFFh and BX=0002h**
  - MUL BL; AX←01FEh (255 * 2 = 510) CF=OF=1
  - IMUL BL; AX←FFFEh (-1 * 2 = -2) CF=OF=0
  - MUL AL; AX←FE01 (255 * 255 = 65025) CF=OF=1
  - IMUL AL; AX←0001 (-1 * -1 = 1) CF=OF=0
  - MUL BX; DX←0001 AX←FFFE CF=OF=1
  - IMUL BX; DX←FFFF AX←FFFE CF=OF=0

Application: Inputting a Decimal Number

- **Inputting a 2-digit decimal number**

```
MOV AH, 1          ;read first digit
INT 21H
SUB AL, '0'        ; convert digit from ASCII code to binary
MOV BL, 10
MUL BL             ; multiply digit by 10
MOV CL, AL
MOV AH, 1          ; read 2nd digit
INT 21H
SUB AL, '0'        ; convert digit from ASCII code to binary
ADD AL, CL         ; AL contains the 2-digit number
```

Division

- **Unsigned division: DIV operand**
- **Signed division: IDIV operand**
- **If operand is a Byte**
  - DIV Operand ; AX ← AX/operand
  - AH= Remainder, AL= Quotient
- **If operand is a Word**
  - DIV Operand ; DX:AX ← DX:AX/operand
  - DX=Remainder, AX= Quotient
- **Operand can be a general register or memory. Cannot be a constant.**
- **All flags are undefined.**

Division - Cont.

- **Divide Overflow**
  - If quotient is too big to fit in specified destination (AL or AX)
  - Happens if divisor much smaller than dividend
  - Program terminates and displays “Divide Overflow”
- **Example: Let DX=0000h, AX=0005h, and BX=FFFEh**
  - DIV BX; AX=0000 DX=0005
  - IDIV BX; AX=FFFE DX=0001
- **Example: Let DX=FFFFh, AX=FFFBh, and BX=0002h**
  - IDIV BX; AX=FFFE DX=FFFF
  - DIV BX; DIVIDE Overflow
- **Example: Let AX=00FBh (251), and BL=FFh**
  - DIV BL; AH=FB AL=00
  - IDIV BL; DIVIDE Overflow

Application: Outputting a Decimal Number

- **Outputting a 2-digit decimal number in AX**

```
MOV BL, 10
DIV BL          ; getting least significant  digit
ADD AH, '0'     ; converting L.S. digit to ASCII
MOV DH, AH      ; storing L.S. digit temporarily
MOV AH, 0
DIV BL          ; getting most significant digit
ADD AH, '0'     ; converting M.S. digit into ASCII
MOV DL, AH      ; displaying M.S. digit
MOV AH, 2
INT 21H
MOV DL, DH      ; displaying least significant digit
INT21H
```


Logic Instructions

- **The AND, OR, and XOR instructions perform named bit-wise logical operation.**
- **Syntax:**
  - AND destination, source
  - OR destination, source
  - XOR destination, source

```
      10101010        10101010        10101010
AND   11110000   OR   11110000   XOR  11110000
     ----------      ----------      ----------
      10100000        11111010        01011010
```

Logic Instructions - Cont.

- **AND instruction used to clear specific destinations bits while preserving others.**
  - A 0 mask bit clears corresponding destination bit
  - A 1 mask bit preserves corresponding destination bit
- **OR instruction used to set specific destinations bits while preserving others.**
  - A 1 mask bit sets corresponding destination bit
  - A 0 mask bit preserves corresponding destination bit
- **XOR instruction used to complement specific destinations bits while preserving others.**
  - A 1 mask bit complements corresponding destination bit
  - A 0 mask bit preserves corresponding destination bit

Logic Instructions - Cont.

- **Effect on flags**
  - SF, ZF, PF change based on result
  - AF undefined
  - CF=OF=0
- **Examples:**
  - Converting ASCII digit to a number
  - SUB AL, 30h
  - AND AL, 0Fh
  - Converting a lowercase letter to uppercase
  - SUB AL, 20h
  - AND AL, 0DFh
  - Initializing register with 0
  - XOR AL, AL

Logic Instructions - Cont.

- **NOT instruction**
  - performs one's complement operation on destination
  - Syntax: NOT destination
  - has no effect on flags.
- **TEST instruction**
  - performs an AND operation of destination with source but does not change destination
  - it affects the flags like the AND instruction
  - used to examine content of individual bits
- **Example**
  - To test for even numbers
  - TEST AL, 1; if ZF=1, number is even

Shift & Rotate Instructions

- **Shift bits in destination operand by one or more bit positions either to left or to right.**
  - For shift instructions, shifted bits are lost
  - For rotate instructions, bits shifted out from one end are put back into other end
- **Syntax:**
  - Opcode destination, 1 ; for single-bit shift or rotate
  - Opcode destination, CL ; for shift or rotate of N bits
- **Shift Instructions:**
  - SHL/SAL: shift left (shift arithmetic left)
  - SHR: shift right
  - SAR: shift arithmetic right

Shift & Rotate Instructions - Cont.

- **Rotate instructions**
  - ROL: rotate left
  - ROR: rotate right
  - RCL: rotate left with carry
  - RCR: rotate right with carry
- **Effect on flags (shift & rotate instructions):**
  - SF, PF, ZF change based on result
  - AF undefined
  - CF= last bit shifted
  - OF=1 if sign bit changes on single-bit shifts

Shift & Rotate Instructions - Cont.

- **Examples: Let AL=FFh**
  - SHR AL, 1 ; AL ← 7Fh
  - SAR AL, 1 ; AL ← FFh
  - SHL AL, 1 ; AL ← FEh
  - SAL AL, 1 ; AL ← FEh
- **Examples: Let AL=0Bh and CL=02h**
  - SHL AL, 1 ; AL ← 16h
  - SHL AL, CL ; AL ← 2Ch
  - SHR AL, 1 ; AL ← 05h
  - SHR AL, CL ; AL ← 02h
  - ROL AL, 1 ; AL ← 16h
  - ROR AL, 1 ; AL ← 85h

Multiplication & Division by Shift

- **Multiplication by left shift**
  - A left shift by 1 bit doubles the destination value, i.e. multiplies it by 2.
- **Division by right shift**
  - A right shift by 1 bit halves it and rounds down to the nearest integer, i.e. divides it by 2.
- **Example: Multiply signed content of AL by 17**
  - MOV AH, AL
  - MOV CL, 4
  - SAL AL, CL ; AL= 16*AL
  - ADD AL, AH; AL=16*AL + AL = 17 AL

Flow Control Instructions

- **Unconditional jump**
  - JMP label ; IP ← label
- **Conditional jump**
  - Signed jumps
  - Unsigned jumps
  - Common jumps
- **Signed jumps**
  - JG/JNLE jump if greater than, or jump if not less than or equal
  - JGE/JNL jump if greater than or equal, or jump if not less than
  - JL/JNGE jump if less than, or jump if not greater than or equal
  - JLE/JNG jump if less than or equal, or jump if not greater than

Flow Control Instructions - Cont.

- **Unsigned jumps**
  - JA/JNBE jump if above, or jump if not below or equal
  - JAE/JNB jump if above or equal, or jump if not below
  - JB/JNAE jump if below, or jump if not above or equal
  - JBE/JNA jump if below or equal, or jump if not above
- **Single-Flag jumps**
  - JE/JZ jump if equal, or jump if equal to zero
  - JNE/JNZ jump if not equal, or jump if not equal to zero
  - JC jump of carry
  - JNC jump if no carry
  - JO jump if overflow
  - JNO jump if no overflow

Flow Control Instructions - Cont.

- **Single-flag jumps**
  - JS jump if sign negative
  - JNS jump if nonnegative sign
  - JP/JPE jump if parity even
  - JNP/JPO jump if parity odd
- **Jump based on CX**
  - JCXZ
- **Loop Instructions**
  - Loop
  - Loopnz/Loopne
  - Loopz/Loope
- **All jump instructions have no effect on the flags.**

Branching Structures: IF-Then

- **Example:**

```
If AX < 0   Then
    Replace AX by –AX
ENDIF

; if AX < 0
        CMP AX, 0
        JNL END_IF
;then
        NEG AX
END_IF:
```


IF-Then-Else

- **Example:**

```
If AL <= BL   Then
    Display character in AL
Else
    Display character in BL
ENDIF

        MOV AH, 2
; if AL<=BL
        CMP AL, BL
        JNBE ELSE_
;then
        MOV DL, AL
        JMP DISPLAY
ELSE_:
        MOV DL, BL
DISPLAY:
        INT 21H
END_IF:
```

CASE

- **Example:**

CASE AX
    <0: put –1 in BX
    =0: put 0 in BX
    >0: put 1 in BX
END_CASE

```
; case AX
            CMP AX, 0
            JL NEGATIVE
            JE ZERO
            JG POSITIVE
NEGATIVE:   MOV BX, -1
            JMP END_CASE
ZERO:       MOV BX, 0
            JMP END_CASE
POSITIVE:   MOV BX, 1
END_CASE:
```


CASE – Cont.

- **Example:**

CASE AL
    1,3: display ‘o’
    2,4: display ‘e’
END_CASE

```
; case AL
            CMP AL, 1       ; 1, 3:
            JE ODD
            CMP AL, 3
            JE ODD
            CMP AL, 2       ; 2, 4:
            JE EVEN
            CMP AL, 4
            JE EVEN
            JMP END_CASE
ODD:        MOV DL, ‘o’
            JMP DISPLAY
EVEN:       MOV DL, ‘e’
DISPLAY:    MOV AH, 2
            INT 21H
END_CASE:
```

Branches with Compound Conditions

- **Example:**

  If (‘A’ <= character) and (character <= ‘Z’) Then
  Display character
  END_IF

```
; read a character
        MOV AH, 1
        INT 21H
; If (‘A’ <= character) and (character <= ‘Z’) Then
        CMP AL, ‘A’
        JNGE END_IF
        CMP AL, ‘Z’
        JNLE END_IF
; display character
        MOV DL, AL
        MOV AH, 2
        INT 21H
END_IF:
```


Branches with Compound Conditions

- **Example:**

  If (character=‘y’) OR (character <= ‘Y’) Then
  Display character
  Else terminate program
  END_IF

```
; read a character
        MOV AH, 1
        INT 21H
; If (character=‘y’) OR (character = ‘Y’) Then
        CMP AL, ‘y’
        JE Then
        CMP AL, ‘Y’
        JE Then
        JMP ELSE_
Then:   MOV AH, 2
        MOV DL, AL
        INT 21H
        JMP END_IF
ELSE:   MOV AH, 4CH
        INT 21H
END_IF:
```

Loop Instructions

- **Loop Next**
  - Dec Cx
  - If CX<>0 JMP Next
- **Loopz/loope Next**
  - Dec Cx
  - If (CX<>0) AND (ZF=1) JMP Next
- **Loopnz/loopne Next**
  - Dec Cx
  - If (CX<>0) AND (ZF=0) JMP Next

FOR LOOP

- **Example:**

```
For 80 times DO
    Display '*'
END_IF
            MOV CX, 80
            MOV AH, 2
            MOV DL, '*'
Next:       INT 21H
            Loop Next
```

While Loop

- **Example:**

  Initialize count to 0
  Read a character
  While character <> Carriage Return DO
    Count = Count + 1
    Read a character
  END_While

```
        MOV DX, 0
        MOV AH, 1
        INT 21H
While_: CMP AL, 0DH
        JE End_While
        INC DX
        INT 21H
        JMP While_
End_While:
```


Repeat Loop

- **Example:**

  Repeat
    Read a character
  Until character is blank

```
        MOV AH, 1
Repeat:
        INT 21H
; until
        CMP AL, ' '
        JNE Repeat
```

Application of Loope

- **Example: Search for a number in a Table**

```
Table DB 1,2,3,4,5,6,7,8,9

        XOR SI, SI
        MOV CX, 9
Next:   INC SI
        CMP Table[SI-1], 7
        Loopne Next
```


The Stack

- **One dimensional data structure**
  - Items added and removed from one end
  - Last-in first-out
- **Instructions**
  - PUSH
  - POP
  - PUSHF
  - POPF
- **PUSH & POP have one operand**
  - 16-bit register or memory word
  - Byte operands are not allowed
  - Constant operands are not allowed

Stack Instructions

- **SP points at the the top of the stack**
- **.STACK 100H**
  - SP is initialized to 100H
- **PUSH operand**
  - SP ← SP - 2
  - [SP+1:SP] ← operand
- **POP operand**
  - Operand ← [SP+1:SP]
  - SP ← SP + 2
- **PUSHF**
  - SP ← SP - 2
  - [SP+1:SP] ← flags register
- **POPF**
  - Flags register ← [SP+1:SP]
  - SP ← SP + 2

Reversing a String

- **String DB "COE-205"**

```
        MOV CX, 7 ; CX contains length of string
        XOR BX, BX
Next:   MOV AL, String[BX]
        PUSH AX
        INC BX
        LOOP Next
        MOV CX, 7
        XOR BX, BX
Next2:  POP AX
        MOV String[BX], AL
        INC BX
        LOOP Next2
```

Procedures

- **Procedure Declaration**

```
Name    PROC    type
;body of the procedure

        RET
Name    ENDP
```

- **Procedure type**
  - NEAR (statement that calls procedure in same segment with procedure)
  - FAR (statement that calls procedure in different segment)
  - Default type is near
- **Procedure Invocation**
  - CALL Name

Procedures – Cont.

- **Executing a CALL instruction causes**
  - Save return address on the stack
    - Near procedure: PUSH IP
    - Far procedure: PUSH CS; PUSH IP
  - IP gets the offset address of the first instruction of the procedure
  - CS gets new segment number if procedure is far
- **Executing a RET instruction causes**
  - Transfer control back to calling procedure
    - Near procedure: POP IP
    - Far procedure: POP IP; POP CS
- **RET n**
  - IP ← [SP+1:SP]
  - SP ← SP + 2 + n

Passing Parameters to Procedures

- **By value using Registers**
- **By address using Registers**
- **Using the stack**
  - Copy SP to BP
  - Access parameters from stack using BP register

Procedure - Example

- **Read a number n from 1-9 and display an array of n x n stars "*"**
  - NL DB 10,13,"$"

```
        MOV AH, 1          ; read a number
        INT 21H
        AND AX, 0FH ; convert number from ASCII
        MOV CX, AX
        MOV BX, AX
Next::  PUSH CX
        PUSH BX
        CALL Display
        POP CX
        MOV AH, 9
        LEA DX, NL
        INT 21H
        Loop Next
Display Proc Near
        MOV BP, SP
        MOV CX, [BP+2]
        MOV AH, 2
        MOV DL, '*'
Next2:  INT 21H
        Loop Next2
        RET 2
Display ENDP
```

IN/OUT Instructions

- **Direct: port number is 0-255**
  - IN AL, port ; AL ←[port]
  - IN AX, port ; AL ←[port] ; AH ←[port+1]
  - OUT port, AL ; [port] ←AL
  - OUT port, AX ; [port] ←AL; [port+1] ←AH
- **Indirect: port number is in DX**
  - IN AL, DX ; AL ←[DX]
  - IN AX, DX ; AL ←[DX] ; AH ←[DX+1]
  - OUT DX, AL ; [DX] ←AL
  - OUT DX, AX ; [DX] ←AL; [DX+1] ←AH

String Instructions

- **Five categories**
  - MOVS, MOVSB, MOVSW
  - CMPS, CMPSB, CMPSW
  - SCAS, SCASB, SCASW
  - LODS, LODSB, LODSW
  - STOS, STOSB, STOSW
- **Source is always in DS:[SI]**
- **Destination is always in ES:[DI]**
- **If DF=0, SI and DI are incremented**
- **If DF=1, SI and DI are decremented**
- **To clear direction flag: CLD**
- **To set direction flag: STD**

String Instructions – Cont.

- **MOVSB**
  - ES:[DI] ← DS:[SI]
  - DI ← DI+1; SI ←SI+1 (if DF=0)
  - DI ← DI-1; SI ←SI-1 (if DF=1)
- **MOVSW**
  - ES:[DI+1:DI] ← DS:[SI+1:SI]
  - DI ← DI+2; SI ←SI+2 (if DF=0)
  - DI ← DI-2; SI ←SI-2 (if DF=1)
- **MOVS destination, source**
  - Replaced by either MOVSB or MOVSW depending on operands size

String Instructions – Cont.

- **CMPSB**
  - DS:[SI] - ES:[DI]
  - DI ← DI+1; SI ←SI+1 (if DF=0)
  - DI ← DI-1; SI ←SI-1 (if DF=1)
- **CMPSW**
  - DS:[SI+1:SI] - ES:[DI+1:DI]
  - DI ← DI+2; SI ←SI+2 (if DF=0)
  - DI ← DI-2; SI ←SI-2 (if DF=1)
- **CMPS destination, source**
  - Replaced by either CMPSB or CMPSW depending on operands size

String Instructions – Cont.

- **SCASB**
  - AL - ES:[DI]
  - DI ← DI+1; (if DF=0)
  - DI ← DI-1 (if DF=1)
- **SCASW**
  - AX - ES:[DI+1:DI]
  - DI ← DI+2; (if DF=0)
  - DI ← DI-2; (if DF=1)
- **SCAS destination**
  - Replaced by either SCASB or SCASW depending on operands size

String Instructions – Cont.

- **LODSB**
  - AL ← DS:[SI]
  - SI ← SI+1; (if DF=0)
  - SI ← SI-1 (if DF=1)
- **LODSW**
  - AX ← DS:[SI+1:SI]
  - SI ← SI+2; (if DF=0)
  - SI ← SI-2; (if DF=1)
- **LODS destination**
  - Replaced by either LODSB or LODSW depending on operands size

String Instructions – Cont.

- **STOSB**
  - ES:[DI] ← AL
  - DI ← DI+1; (if DF=0)
  - DI ← DI-1 (if DF=1)
- **STOSW**
  - ES:[DI+1:DI] ← AX
  - DI ← DI+2; (if DF=0)
  - DI ← DI-2 (if DF=1)
- **STOS destination**
  - Replaced by either STOSB or STOSW depending on operands size

Copying a String to another

```
.DATA
    String1 DB “Hello”
    String2 DB 5 dup(?)
.CODE
            MOV AX, @DATA
            MOV DS, AX
            MOV ES, AX
            CLD
            MOV CX, 5
            LEA SI, String1
            LEA DI, String2
    REP     MOVSB
```

Copying a String to another in Reverse Order

```
.DATA
    String1 DB “Hello”
    String2 DB 5 dup(?)
.CODE
            MOV AX, @DATA
            MOV DS, AX
            MOV ES, AX
            STD
            MOV CX, 5
            LEA SI, String1+4
            LEA DI, String2
    Next:   MOVSB
            ADD DI, 2
            LOOP Next
```