The x86 PC

assembly language, design, and interfacing

fifth edition

Prentice Hall

INT 21H and INT 10H Programming and Macros

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OBJECTIVES
this chapter enables the student to:

- Use INT 10H function calls to:
  - Clear the screen.
  - Set the cursor position.
  - Write characters to the screen in text mode.
  - Draw lines on the screen in graphics mode.
  - Change the video mode.
- Use INT 21H function calls to:
  - Input characters from the keyboard.
  - Output characters to the screen.
  - Input or output strings.

OBJECTIVES (cont)

this chapter enables the student to:

- Use the LABEL directive to set up structured data items.
- Code Assembly language instructions to define and invoke macros.
- Explain how macros are expanded by the assembler.
- Use the LOCAL directive to define local variables within macros.
- Use the INCLUDE directive to retrieve macros from other files.

4.0: INT 21H and 10H

- The INT instruction is somewhat like a FAR call.
  - Saves CS:IP and the flags on the stack and goes to the subroutine associated with that interrupt.

```
INT  xx;the interrupt number xx can be 00 - FFH
```

  - In x86 processors, 256 interrupts, numbered 00 to FF.
    - INT 10H and INT 21H are the most widely used with various functions selected by the value in the AH register.

4.1: BIOS INT 10H PROGRAMMING

- INT 10H subroutines are burned into the ROM BIOS.
  - Used to communicate with the computer's screen video.
    - Manipulation of screen text/graphics can be done via INT 10H.
- Among the functions associated with INT 10H are changing character or background color, clearing the screen, and changing the location of the cursor.
  - Chosen by putting a specific value in register AH.

4.1: BIOS INT 10H PROGRAMMING
monitor screen in text mode

- The monitor screen in the x86 PC is divided into 80 columns and 25 rows in normal text mode.
  - Columns are numbered from 0 to 79.
  - Rows are numbered 0 to 24.

The top left corner has been assigned 00,00, the top right 00,79.

Bottom left is 24,00, bottom right 24,79.

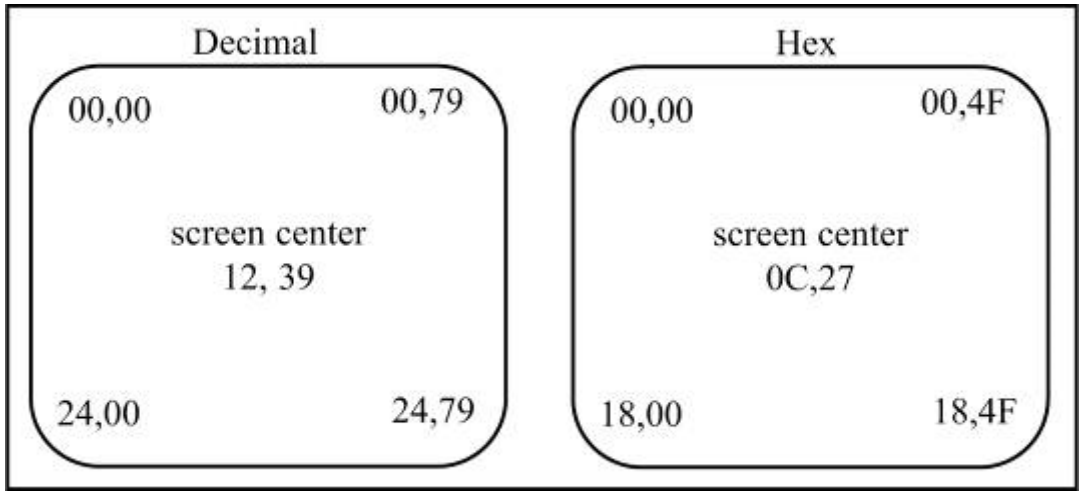


Figure 4-1 Cursor Locations (row, column)

4.1: BIOS INT 10H PROGRAMMING
screen clearing with INT 10H function 06H

- To clear the screen using INT 10H, these registers must contain certain values before INT 10H is called:
  - AH = 06, AL = 00, BH = 07, CX = 0000, DH = 24, DL = 79.

```
MOV    AH,06     ;AH=06 to select scroll function
MOV    AL,00     ;AL=00 the entire page
MOV    BH,07     ;BH=07 for normal attribute
MOV    CH,00     ;CH=00 row value of start point
MOV    CL,00     ;CL=00 column value of start point
MOV    DH,24     ;DH=24 row value of ending point
MOV    DL,79     ;DL=79 column value of ending point
INT    10H       ;invoke the interrupt
```

  - Option **AH = 06** calls the scroll function, to scroll upward.
  - **CH** & **CL** registers hold starting row & column.
  - **DH** & **DL** registers hold ending row & column.

4.1: BIOS INT 10H PROGRAMMING
setting the cursor to a specific location

- INT 10H function AH = 02 will change the position of the cursor to any location.
  - Desired position is identified by row/column values in DX.
    - Where DH = row and DL = column.
- Video RAM can have multiple pages of text.
  - When AH = 02, page zero is chosen by making BH = 00.
- After INT 10H (or INT 21H) has executed, registers not used by the interrupt remain unchanged.

4.1: BIOS INT 10H PROGRAMMING
setting the cursor to a specific location

- Example 4-1 demonstrates setting the cursor to a specific location.

Example 4-1

Write the code to set the cursor position to row = 15 = 0FH and column = 25 = 19H.

Solution:

```
MOV   AH,02       ;set cursor option
MOV   BH,00       ;page 0
MOV   DL,25       ;column position
MOV   DH,15       ;row position
INT   10H         ;invoke interrupt 10H
```

4.1: BIOS INT 10H PROGRAMMING
get current cursor position

- In text mode, determine where the cursor is located at any time by executing the following:

```
MOV    AH,03          ;option 03 of BIOS INT 10H
MOV    BH,00          ;page 00
INT    10H            ;interrupt 10H routine
```

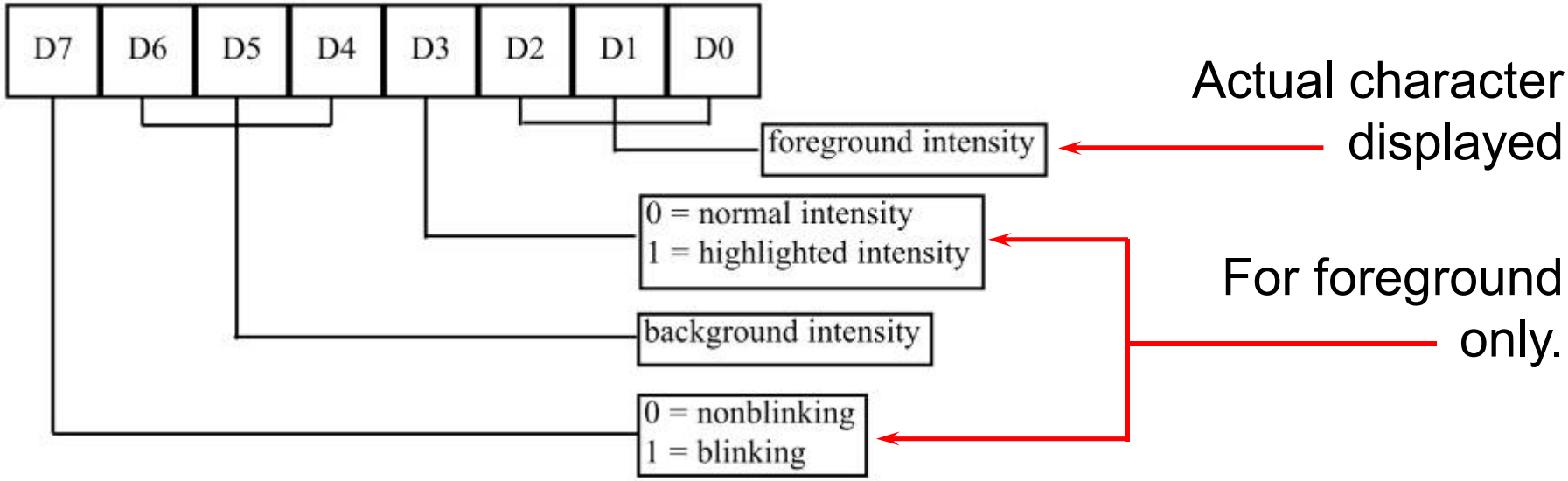
  - After execution of the program, registers DH & DL will have current row and column positions.
    - CX provides information about the shape of the cursor.
  - In text mode, **page 00** is chosen for the currently viewed page.

4.1: BIOS INT 10H PROGRAMMING
changing the video mode

- To change the video mode, use INT 10H with AH = 00 and AL = video mode.

4.1: BIOS INT 10H PROGRAMMING
attribute byte in monochrome monitors

- An attribute associated with each character on the screen provides information to the video circuitry.
  - Character (foreground) & background color/intensity.
- The attribute byte for each character on the monochrome monitor is limited.



4.1: BIOS INT 10H PROGRAMMING
attribute byte in monochrome monitors

Example 4-3

Write a program using INT 10H to:
(a) Change the video mode.
(b) Display the letter "D" in 200H locations with attributes black on white blinking (blinking letters "D" are black and the screen background is white).
(c) Then use DEBUG to run and verify the program.

Solution:
(a) INT 10H function AH = 00 is used with AL = video mode to change the video mode. Use AL = 03.

```
MOV    AH,00        ;SET MODE OPTION
MOV    AL,03        ;CHANGE VIDEO MODE
INT    10H
```

See the entire example on page 134 of your textbook.

Possible variations of attributes in Fig. 4-2.

Binary	Hex	Result
0000 0000	00	white on white (no display)
0000 0111	07	white on black normal
0000 1111	0F	white on black highlight
1000 0111	87	white on black blinking
0111 0111	77	black on black (no display)
0111 0000	70	black on white
1111 0000	F0	black on white blinking

4.1: BIOS INT 10H PROGRAMMING
attribute byte in CGA text mode

- CGA mode is the common denominator for all color monitors, as S all color monitors & video circuitry are upwardly compatible,
  - CGA attribute byte bit definition is as shown:

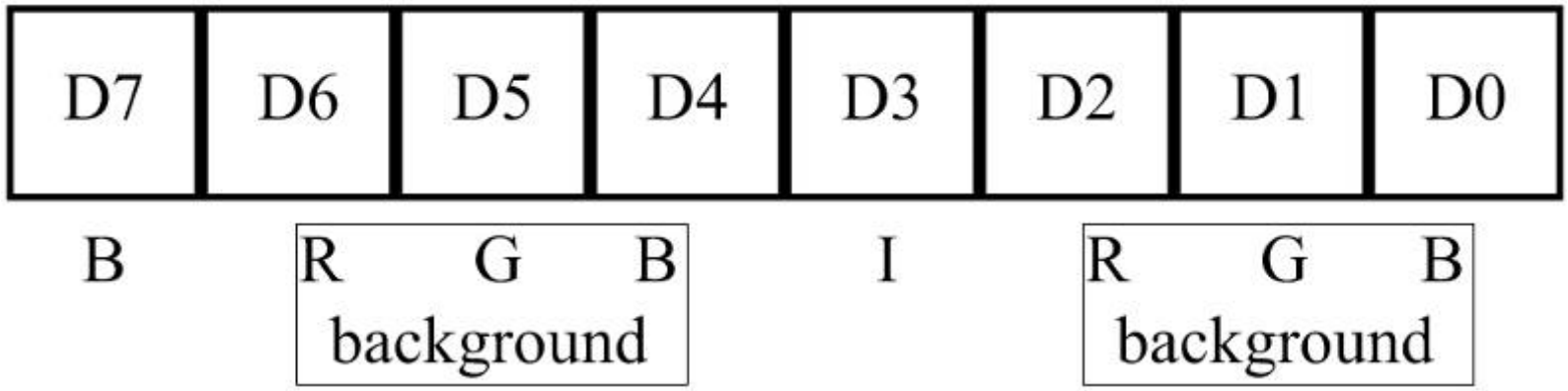


Figure 4-3 CGA Attribute Byte

4.1: BIOS INT 10H PROGRAMMING
attribute byte in CGA text mode

- The background can take eight different colors by combining the prime colors **red**, **blue**, and **green**.
- The foreground can be any of 16 different colors by combining **red**, **blue**, **green**, and **intensity**

Example 4-4

Write a program that puts 20H (ASCII space) on the entire screen. Use high-intensity white on a blue background attribute for characters.

Solution:

```
MOV   AH,00     ;SET MODE OPTION
MOV   AL,03     ;CGA COLOR TEXT MODE OF 80×25
INT   10H
MOV   AH,09     ;DISPLAY OPTION
MOV   BH,00     ;PAGE 0
MOV   AL,20H    ;ASCII FOR SPACE
MOV   CX,800H   ;REPEAT IT 800H TIMES
MOV   BL,1FH    ;HIGH-INTENSITY WHITE ON BLUE
INT   10H
```

Example 4-4 shows the use of the attribute byte in CGA mode.

4.1: BIOS INT 10H PROGRAMMING
attribute byte in CGA text mode

Table 4-1: The 16 Possible Colors

I	R	G	B	Color
0	0	0	0	black
0	0	0	1	blue
0	0	1	0	green
0	0	1	1	cyan
0	1	0	0	red
0	1	0	1	magenta
0	1	1	0	brown
0	1	1	1	white
1	0	0	0	gray
1	0	0	1	light blue
1	0	1	0	light green
1	0	1	1	light cyan
1	1	0	0	light red
1	1	0	1	light magenta
1	1	1	0	yellow
1	1	1	1	high intensity white

Some possible CGA colors and variations.

Binary	Hex	Color effect
0000 0000	00	Black on black
0000 0001	01	Blue on black
0001 0010	12	Green on blue
0001 0100	14	Red on blue
0001 1111	1F	High-intensity white on blue

4.1: BIOS INT 10H PROGRAMMING graphics: pixel resolution & color

- In text mode, the screen is viewed as a matrix of rows and columns of characters.
  - In graphics mode, a matrix of horizontal & vertical pixels.
    - Number of pixels depends on monitor resolution & video board.
- Two facts associated with every pixel on the screen must be stored in the video RAM:
  - Location of the pixel, and Attributes. (color and intensity)
    - The higher the number of pixels and colors, the larger the amount of memory that is needed to store them
    - Memory requirements go up with resolution & number of colors.
  - CGA mode can have a maximum of 16K bytes of video memory due to its inherent design structure.

4.1: BIOS INT 10H PROGRAMMING
graphics: modes

- Text mode of 80 × 25 characters.
  - A total of 2K (80 × 25 = 2000) for characters, plus 2K for attributes, as each character has one attribute byte.
    - Each screen (frame) takes 4K, which results in CGA supporting a total of four pages of data, where each page represents one full screen.
- In this mode, 16 colors are supported.
  - To select this mode, use AL = 03 for mode selection in INT 10H option AH = 00.

4.1: BIOS INT 10H PROGRAMMING
graphics: modes

- Graphics mode of 320 × 200. (medium resolution)
  - 64,000 pixels. (320 columns × 200 rows = 64,000)
    - Dividing total video RAM of 128K bits (16K × 8 bits = 128K) by 64,000 pixels gives 2 bits for the color of each pixel.
- 2 bits give four possibilities, thus 320 × 200 resolution CGA can support no more than 4 colors.
  - To select this mode, use AL = 04.

4.1: BIOS INT 10H PROGRAMMING
graphics: modes

- Graphics resolution of 640 × 200. (high resolution)
  - 128,000 pixels. (200 × 640 = 128,000)
    - Dividing gives 1 bit (128,000/128,000 = 1) for color, which can can be on (white) or off (black).
- 640 × 200 high-resolution CGA can support only black and white.
  - To select this mode, use AL = 06.
- With a fixed amount of video RAM, the number of supported colors decreases as resolution increases.
  - To create more colors in video boards there must be memory available to store the extra colors.

4.1: BIOS INT 10H PROGRAMMING
INT 10H and pixel programming

- To address a single pixel on the screen, use INT 10H with AH = 0CH.
  - The X (column) and Y (row) coordinates of the pixel must be known, and vary, depending on monitor resolution.
    - Registers are CX = the column point (the X coordinate) and DX = the row point. (Y coordinate)
  - To turn the pixel on/off, AL=1 or AL=0 for black and white.
    - The value of AL can be modified for various colors.
- If the display mode supports more than one page, BH = page number.

4.1: BIOS INT 10H PROGRAMMING
drawing lines in graphics mode

- To draw a horizontal line, choose row/column values to point to the beginning of the line and increment the column until it reaches the end of the line.
  - To draw a vertical line, increment the vertical value held by the DX register, and keep CX constant.
  - Linear equation $y = mx + b$ can be used for any line.

4.1: BIOS INT 10H PROGRAMMING
drawing lines in graphics mode

Drawing a horizontal line

Example 4-5

Write a program to: (a) clear the screen, (b) set the mode to CGA of 640 × 200 resolution, and (c) draw a horizontal line starting at column = 100, row = 50, and ending at column 200, row 50.

Solution:

```
        MOV   AX,0600H     ;SCROLL THE SCREEN
        MOV   BH,07        ;NORMAL ATTRIBUTE
        MOV   CX,0000      ;FROM ROW=00,COLUMN=00
        MOV   DX,184FH     ;TO ROW=18H,COLUMN=4FH
        INT   10H          ;INVOKE INTERRUPT TO CLEAR SCREEN
        MOV   AH,00        ;SET MODE
        MOV   AL,06        ;MODE = 06 (CGA HIGH RESOLUTION)
        INT   10H          ;INVOKE INTERRUPT TO CHANGE MODE
        MOV   CX,100       ;START LINE AT COLUMN =100 AND
        MOV   DX,50        ;ROW = 50
BACK:   MOV   AH,0CH       ;AH=0CH TO DRAW A LINE
        MOV   AL,01        ;PIXELS = WHITE
        INT   10H          ;INVOKE INTERRUPT TO DRAW LINE
        INC   CX           ;INCREMENT HORIZONTAL POSITION
        CMP   CX,200       ;DRAW LINE UNTIL COLUMN = 200
        JNZ   BACK
```

4.2: DOS INTERRUPT 21H

- In previous chapters, a fixed set of data was defined in the data segment & results viewed in a memory dump.
  - This section uses information inputted from the keyboard, and displayed on the screen.
    - A much more dynamic way of processing information.
- When the OS is loaded, INT 21H can be invoked to perform some extremely useful functions.
  - Commonly referred to as DOS INT 21H function calls.
    - In contrast to BIOS-ROM based INT 10H.

4.2: DOS INTERRUPT 21H Option 09 outputting a data string the monitor

- INT 21H can send a set of ASCII data to the monitor.
  - Set AH = 09 and DX = offset address of the ASCII data.
    - Displays ASCII data string pointed at by DX until it encounters the dollar sign "$".
- The data segment and code segment, to display the message *"The earth is but one country"* :

```
DATA_ASC    DB    'The earth is but one country','$'

MOV    AH,09              ;option 09 to display string of data
MOV    DX,OFFSET DATA_ASC      ;DX= offset address of data
INT    21H                     ;invoke the interrupt
```

4.2: DOS INTERRUPT 21H Option 02 outputting a single character

- To output only a single character, **02** is put in **AH**, and **DL** is loaded with the character to be displayed.
- The following displays the letter *"J"* :

```
MOV     AH,02           ;option 02 displays one character
MOV     DL,'J'          ;DL holds the character to be displayed
INT     21H             ;invoke the interrupt
```

  - This option can also be used to display '$' on the monitor as the string display option (option 09) will not display '$‘.

4.2: DOS INTERRUPT 21H Option 01 inputting a single character, with echo

- This functions waits until a character is input from the keyboard, then echoes it to the monitor.
  - After the interrupt, the input character will be in AL.

```
MOV   AH,01 ;option 01 inputs one character
INT   21H   ;after the interrupt, AL = input character (ASCII)
```

4.2: DOS INTERRUPT 21H Option 01 inputting a single character, with echo

- Program 4-1 combines INT 10H and INT 21H.

```
TITLE       PROG4-1 SIMPLE DISPLAY PROGRAM
PAGE        60,132
            .MODEL SMALL
            .STACK       64
;-----------------------------
            .DATA
MESSAGE     DB    'This is a test of
                   the display routine','$'
;-----------------------------
      .CODE
MAIN  PROC  FAR
      MOV   AX,@DATA
      MOV   DS,AX
      CALL  CLEAR         ;CLEAR THE SCREEN
      CALL  CURSOR        ;SET CURSOR POSITION
      CALL  DISPLAY       ;DISPLAY MESSAGE
      MOV   AH,4CH
      INT   21H           ;GO BACK TO DOS
MAIN  ENDP
```

The program does the following:

(1) Clears the screen.

(2) Sets the cursor to the center of the screen.

(3) Displays the message *"This is a test of the display routine".*

See the entire program listing on page 139 of your textbook.

4.2: DOS INTERRUPT 21H Option 0AH inputting a data string from the keyboard

- A means by which one can get keyboard data from & store it in a predefined data segment memory area.
  - Register AH = 0AH.
  - DX = offset address at which the string of data is stored.
    - Commonly referred to as a buffer area.
- DOS requires a buffer area be defined in the data segment.
  - The first byte specifies the size of the buffer.
  - The number of characters from the keyboard is in the second byte.
  - Keyed-in data placed in the buffer starts at the third byte.

4.2: DOS INTERRUPT 21H Option 0AH inputting a data string from the keyboard

- This program accepts up to six characters from the keyboard, including the return (carriage return) key.
  - Six buffer locations were reserved, and filled with FFH.

```
ORG    0010H
DATA1  DB     6,?,6 DUP (FF);0010H=06, 0012H to 0017H = FF

       MOV    AH,0AH              ;string input option of INT 21H
       MOV    DX,OFFSET DATA1     ;load offset address of buffer
       INT    21H                 ;invoke interrupt 21H
```

  - Memory contents of offset 0010H:

0010	0011	0012	0013	0014	0015	0016	0017
06	00	FF	FF	FF	FF	FF	FF

  - The PC won't exit INT 21H until it encounters a RETURN.

4.2: DOS INTERRUPT 21H Option 0AH inputting a data string from the keyboard

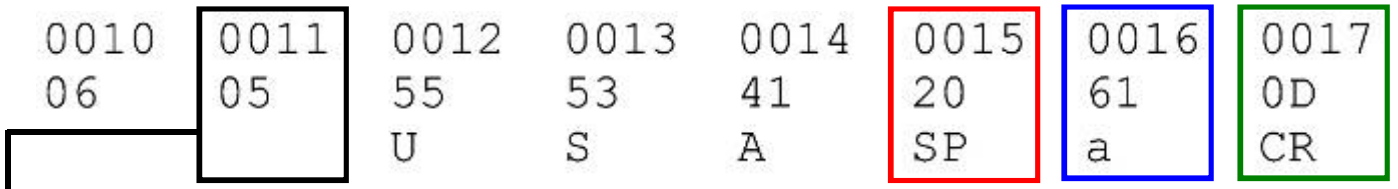
- Assuming the data entered through the keyboard was "USA" <RETURN>, the contents of memory locations starting at offset 0010H would look like:

```
0010   0011   0012   0013   0014   0015   0016   0017
06     03     55     53     41     0D     FF     FF
USACR
```

  - **0010H = 06** DOS requires the size of the buffer here.
  - **0011H = 03** The keyboard was activated three times (excluding the RETURN key) to key in letters **U**, **S**, and **A**.
  - **0012H = 55H** ASCII hex value for letter **U**.
  - **0013H = 53H** ASCII hex value for letter **S**.
  - **0014H = 41H** ASCII hex value for letter **A**.
  - **0015H = 0DH** ASCII hex value for **CR**. (carriage return)

4.2: DOS INTERRUPT 21H
inputting more than buffer size

- Entering more than six characters (five + the CR = 6) will cause the computer to sound the speaker.
  - The contents of the buffer will look like this:



  - Location **0015** has **ASCII 20H** for <SPACE>
  - Location **0016** has **ASCII 61H** for "a".
  - Location **0017** has **0D** for <RETURN> key.
  - The actual length is **05** at memory offset **0011H**.

4.2: DOS INTERRUPT 21H
inputting more than buffer size

- If only the CR key is activated & no other character:

```
        ORG    20H
DATA4   DB     10,?,10 DUP (FF)
```

  - **0AH** is placed in memory 0020H.
  - **0021H** is for the count.
  - 0022H IS the first location to have data that was entered.

0020	0021	0022	0023	0024	0025	0026
0A	00	0D	FF	FF	FF	FF

0027	0028	0029	002A	002B	002C
FF	FF	FF	FF	FF	FF

CR is *not* included in the count.

  - If only the <RETURN> key is activated, **0022H** has **0DH**, the hex code for CR.
    - The actual number of characters entered is **0** at location **0021**.

4.2: DOS INTERRUPT 21H
use of carriage return and line feed

- In Program 4-2, the EQU statement is used to equate CR (carriage return) with its ASCII value of 0DH, and LF (line feed) with its ASCII value of 0AH.
  - See pages 141 & 142
- Program 4-3 prompts the user to type in a name with a maximum of eight letters.
  - The program gets the length and prints it to the screen.
  - See page 143.
- Program 4-4 demonstrates many functions described in this chapter.
  - See pages 144 & 145.

4.2: DOS INTERRUPT 21H Option 07 keyboard input without echo

- Option 07 requires the user to enter a single character, which is not displayed (or echoed) on the screen.
  - The PC waits until a single character is entered and provides the character in AL.

```
MOV    AH,07 ;keyboard input without echo
INT    21H
```

4.2: DOS INTERRUPT 21H
using LABEL to define a string buffer

- The LABEL directive can be used in the data segment to assign multiple names to data.

```
name   LABEL attribute
```

  - Used to assign the same offset address to two names.
  - The attribute can be:
    - BYTE; WORD; DWORD; FWORD; QWORD; TBYTE.
- In the following:

```
JOE    LABEL BYTE
TOM    DB    20 DUP(0)
```

  - The offset address assigned to ***JOE*** is the same offset address for ***TOM*** since the LABEL directive does not occupy any memory space.

4.2: DOS INTERRUPT 21H
using LABEL to define a string buffer

- Use this directive to define a buffer area for the string keyboard input:

```
DATA_BUF     LABEL BYTE
MAX_SIZE     DB    10
BUF_COUNT    DB    ?
BUF_AREA     DB    10 DUP(20H)
```

- In the code segment the data can be accessed by name as follows:

```
MOV   AH,0AH       ;load string into buffer
MOV   DX,OFFSET DATA_BUF
INT   21H
MOV   CL,BUF_COUNT;load the actual length of string
MOV   SI,OFFSET BUF_AREA;SI=address of first byte of string
```

4.3: WHAT IS A MACRO, AND HOW IS IT USED?

- There are applications in Assembly language programming where a group of instructions performs a task used repeatedly.
  - It does not make sense to rewrite them every time.
- Macros allow the programmer to write the task once only & invoke it whenever, wherever it is needed.
  - Reduces time to write code & reduce possibility of errors.

4.3: WHAT IS A MACRO, AND HOW IS IT USED?
MACRO definition

- Every macro definition must have three parts:

```
name   MACRO dummy1,dummy2,...,dummyN
...    ...
...    ...
       ENDM
```

  - The MACRO directive indicates the beginning of the macro definition, ENDM directive signals the end.
    - In between is the *body* of the macro.
  - The name must be unique and must follow Assembly language naming conventions.
    - Dummies are names, parameters, or registers that are mentioned in the body of the macro.
    - The macro can be invoked (or called) by its name, and appropriate values substituted for dummy parameters.

4.3: WHAT IS A MACRO, AND HOW IS IT USED?
MACRO definition

- A macro for displaying a string of data using the widely used function 09 of INT 21H:

```
STRING      MACRO DATA1
            MOV   AH,09
            MOV   DX,OFFSET DATA1
            INT   21H
            ENDM
```

4.3: WHAT IS A MACRO, AND HOW IS IT USED?
MACRO definition

- In the following code segment, the macro can be invoked by its name with the user's actual data:
  - Instruction "STRING MESSAGE1" invokes the macro.

```
MESSAGE1    DB          'What is your name?','$'
            ...
            STRING      MESSAGE1
```

  - The assembler expands the macro by providing the following code in the .LST file:

```
1   MOV     AH,09
1   MOV     DX,OFFSET MESSAGE1
1   INT     21H
```

  - The (1) indicates that the code is from the macro.
    - Earlier versions of MASM, used a plus sign (+).

4.3: WHAT IS A MACRO, AND HOW IS IT USED?
comments in a macro

- Two types of comments in the macro:
  - Listable; Nonlistable.
- Comments preceded by one semicolon (;) will show up in the ".lst" file when the program is assembled.
  - Those preceded by a double semicolon (;;) will not.

4.3: WHAT IS A MACRO, AND HOW IS IT USED?
comments in a macro

- Three directives designed to make programs that use macros more readable, affecting the ".lst" file, with no effect on the ".obj" or ".exe" files:
  - **.LALL (List ALL)** will list all instructions/comments preceded by a single semicolon in the ".lst" file.
  - **.SALL (Suppress ALL)** suppresses the listing of the macro body and the comments.
    - Used to make the list file shorter and easier to read
      - Will not eliminate any opcode from the object file.
  - **.XALL (eXecutable ALL)** is used to list only the part of the macro that generates opcodes.
    - The default listing directive.

4.3: WHAT IS A MACRO, AND HOW IS IT USED?
LOCAL directive and its use in macros

- If a macro is expanded more than once, and there is a label in the label field of the body of the macro, these labels must be declared as LOCAL.
  - Otherwise, an assembler error would be generated when the same label was encountered in two or more places.
- Rules which must be observed in the macro body:
  - 1. All labels in the label field must be declared LOCAL.
  - 2. LOCAL directive must be right after the MACRO directive.
  - 3. The LOCAL directive can be used to declare all names and labels at once.

```
LOCAL name1,name2,name3
```

4.3: WHAT IS A MACRO, AND HOW IS IT USED?
LOCAL directive and its use in macros

- In example 4-7, the "BACK" label is defined as LOCAL right after the MACRO directive.

Example 4-7

Write a macro that multiplies two words by repeated addition, then saves the result.

Solution:

The following macro can be expanded as often as desired in the same program since the label "back" has been declared as LOCAL.

```
MULTIPLY MACRO   VALUE1, VALUE2, RESULT
     LOCAL BACK
;    THIS MACRO COMPUTES RESULT = VALUE1 X VALUE2
;;   BY REPEATED ADDITION
;;VALUE1 AND VALUE2 ARE WORD OPERANDS; RESULT IS A DOUBLEWORD
            MOV   BX,VALUE1    ;BX=MULTIPLIER
            MOV   CX,VALUE2    ;CX=MULTIPLICAND
            SUB   AX,AX        ;CLEAR AX
            MOV   DX,AX        ;CLEAR DX
BACK:       ADD   AX,BX        ;ADD BX TO AX
            ADC   DX,00        ;ADD CARRIES IF THERE IS ONE
            LOOP  BACK         ;CONTINUE UNTIL CX=0
            MOV   RESULT,AX    ;SAVE THE LOW WORD
            MOV   RESULT+2,DX ;SAVE THE HIGH WORD
            ENDM
```

4.3: WHAT IS A MACRO, AND HOW IS IT USED?
INCLUDE directive

- The INCLUDE directive allows a programmer to write macros, save them in a file, and later bring them into any file.
  - Used to bring this file into any ".asm" file, to allow the program can call any of the macros as needed.
    - See Program 4 -7 on pages 155-157.
- In the list file of Program 4-7, the letter "C" in front of the lines indicates that they are copied from another file and included in the present file.

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