# Display Memory

Chapter 6 – Textbook

# Display Memory

- The debugger gives a very close vision of the processor.
- That is why every program written till now was executed inside the debugger.
- Also the debugger is a very useful tool in assembly language program development, since many bugs only become visible when each instruction is independently monitored the way the debugger allows us to do.
- We will now be using the display screen in character mode, the way DOS uses this screen.
- The way we will access this screen is specific to the IBM PC.

# ASCII Codes

- The computer listens, sees, and speaks in numbers. Even a character is a number inside the computer.
- For example the keyboard is labeled with characters however when we press ‘A’, a specific number is transferred from the keyboard to the computer.
- Our program interprets that number as the character ‘A’.
- When the same number comes on display, the Video Graphics Adapter (VGA) in our computer shows the shape of ‘A’.
- Even the shape is stored in binary numbers with a one bit representing a pixel on the screen that is turned on and a zero bit representing a pixel that is not glowing.
- This example is considering a white on black display and no colors.
- This is the way a shape is drawn on the screen.
- The interpretation of ‘A’ is performed by the VGA card, while the monitor or CRT (cathode ray tube) only glows the pixels on and turns them off.
- The keyboard has a key labeled ‘A’ and pressing it the screen shows ‘A’ but all that happened inside was in numbers.

# ASCII Codes

- An ‘A’ on any computer and any operating system is an ‘A’ on every other computer and operating system.
- This is because a standard numeric representation of all commonly used characters has been developed.
- This is called the ASCII code, where ASCII stands for American Standard Code for Information Interchange.
- The name depicts that this is a code that allows the interchange of information; ‘A’ written on one computer will remain an ‘A’ on another.
- The ASCII table lists all defined characters and symbols and their standardized numbers.
- All ASCII based computers use the same code.
- There are few other standards like EBCDIC and gray codes, but ASCII has become the most prevalent standard and is used for Internet communication as well.
- It has become the de facto standard for global communication.
- The character mode displays of our computer use the ASCII standard.
- Some newer operating systems use a new standard Unicode but it is not relevant to us in the current discussion.

# ASCII Codes

- Standard ASCII has 128 characters with numbers assigned from 0 to 127.
- When IBM PC was introduced, they extended the standard ASCII and defined 128 more characters.
- Thus extending the total number of symbols from 128 to 256 numbered from 0 to 255 fitting in an 8-bit byte.
- The newer characters were used for line drawing, window corners, and some non-English characters.
- The need for these characters was never felt on teletype terminals, but with the advent of IBM PC and its full screen display, these semi-graphics characters were the need of the day.
- Keep in mind that at that time there was no graphics mode available.

# ASCII Codes

- The extended ASCII code is just a de facto industry standard but it is not defined by an organization like the standard ASCII.
- Printers, displays, and all other peripherals related to the IBM PC understand the ASCII code.
- If the code for ‘A’ is sent to the printer, the printer will print the shape of ‘A’, if it is sent to the display, the VGA card will form the shape of ‘A’ on the CRT. If it is sent to another computer via the serial port, the other computer will understand that this is an ‘A’.
- The important thing to observe in the ASCII table is the contiguous arrangement of the uppercase alphabets (41-5A), the lowercase alphabets (61-7A), and the numbers (30-39).
- This helps in certain operations with ASCII, for example converting the case of characters by adding or subtracting 0x20 from it. It also helps in converting a digit into its ASCII representation by adding 0x30 to it.

# ASCII Table

| Decimal | Hex | Char | Decimal | Hex | Char | Decimal | Hex | Char | Decimal | Hex | Char |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | [NULL] | 32 | 20 | [SPACE] | 64 | 40 | @ | 96 | 60 | ` |
| 1 | 1 | [START OF HEADING] | 33 | 21 | ! | 65 | 41 | A | 97 | 61 | a |
| 2 | 2 | [START OF TEXT] | 34 | 22 | " | 66 | 42 | B | 98 | 62 | b |
| 3 | 3 | [END OF TEXT] | 35 | 23 | # | 67 | 43 | C | 99 | 63 | c |
| 4 | 4 | [END OF TRANSMISSION] | 36 | 24 | $ | 68 | 44 | D | 100 | 64 | d |
| 5 | 5 | [ENQUIRY] | 37 | 25 | % | 69 | 45 | E | 101 | 65 | e |
| 6 | 6 | [ACKNOWLEDGE] | 38 | 26 | & | 70 | 46 | F | 102 | 66 | f |
| 7 | 7 | [BELL] | 39 | 27 | ' | 71 | 47 | G | 103 | 67 | g |
| 8 | 8 | [BACKSPACE] | 40 | 28 | ( | 72 | 48 | H | 104 | 68 | h |
| 9 | 9 | [HORIZONTAL TAB] | 41 | 29 | ) | 73 | 49 | I | 105 | 69 | i |
| 10 | A | [LINE FEED] | 42 | 2A | * | 74 | 4A | J | 106 | 6A | j |
| 11 | B | [VERTICAL TAB] | 43 | 2B | + | 75 | 4B | K | 107 | 6B | k |
| 12 | C | [FORM FEED] | 44 | 2C | , | 76 | 4C | L | 108 | 6C | l |
| 13 | D | [CARRIAGE RETURN] | 45 | 2D | - | 77 | 4D | M | 109 | 6D | m |
| 14 | E | [SHIFT OUT] | 46 | 2E | . | 78 | 4E | N | 110 | 6E | n |
| 15 | F | [SHIFT IN] | 47 | 2F | / | 79 | 4F | O | 111 | 6F | o |
| 16 | 10 | [DATA LINK ESCAPE] | 48 | 30 | 0 | 80 | 50 | P | 112 | 70 | p |
| 17 | 11 | [DEVICE CONTROL 1] | 49 | 31 | 1 | 81 | 51 | Q | 113 | 71 | q |
| 18 | 12 | [DEVICE CONTROL 2] | 50 | 32 | 2 | 82 | 52 | R | 114 | 72 | r |
| 19 | 13 | [DEVICE CONTROL 3] | 51 | 33 | 3 | 83 | 53 | S | 115 | 73 | s |
| 20 | 14 | [DEVICE CONTROL 4] | 52 | 34 | 4 | 84 | 54 | T | 116 | 74 | t |
| 21 | 15 | [NEGATIVE ACKNOWLEDGE] | 53 | 35 | 5 | 85 | 55 | U | 117 | 75 | u |
| 22 | 16 | [SYNCHRONOUS IDLE] | 54 | 36 | 6 | 86 | 56 | V | 118 | 76 | v |
| 23 | 17 | [ENG OF TRANS. BLOCK] | 55 | 37 | 7 | 87 | 57 | W | 119 | 77 | w |
| 24 | 18 | [CANCEL] | 56 | 38 | 8 | 88 | 58 | X | 120 | 78 | x |
| 25 | 19 | [END OF MEDIUM] | 57 | 39 | 9 | 89 | 59 | Y | 121 | 79 | y |
| 26 | 1A | [SUBSTITUTE] | 58 | 3A | : | 90 | 5A | Z | 122 | 7A | z |
| 27 | 1B | [ESCAPE] | 59 | 3B | ; | 91 | 5B | [ | 123 | 7B | { |
| 28 | 1C | [FILE SEPARATOR] | 60 | 3C | < | 92 | 5C | \ | 124 | 7C | \| |
| 29 | 1D | [GROUP SEPARATOR] | 61 | 3D | = | 93 | 5D | ] | 125 | 7D | } |
| 30 | 1E | [RECORD SEPARATOR] | 62 | 3E | > | [illegible] | [illegible] | ^ | 126 | 7E | ~ |
| 31 | 1F | [UNIT SEPARATOR] | 63 | 3F | ? | 95 | 5F | _ | 127 | 7F | [DEL] |

ASCII-Table-wide

# Display Memory Formation

- We will explore the working of the display with ASCII codes, since it is our immediately accessible hardware.
- When 0x40 is sent to the VGA card, it will turn pixels on and off in such a way that a visual representation of ‘A’ appears on the screen. It has no reality, just an interpretation.
- In later chapters we will program the VGA controller to display a new shape when the ASCII of ‘A’ is received by it.
- The video device is seen by the computer as a memory area containing the ASCII codes that are currently displayed on the screen and a set of I/O ports controlling things like the resolution, the cursor height, and the cursor position.
- The VGA memory is seen by the computer just like its own memory. There is no difference; rather the computer doesn’t differentiate, as it is accessible on the same bus as the system memory.
- Therefore if that appropriate block of the screen is cleared, the screen will be cleared.
- If the ASCII of ‘A’ is placed somewhere in that block, the shape of ‘A’ will appear on the screen at a corresponding place.

# Display Memory Formation

- This correspondence must be defined as the memory is a single dimensional space while the screen is two dimensional having 80 rows and 25 columns. The memory is linearly mapped on this two dimensional space, just like a two dimensional is mapped in linear memory.
- There is one word per character in which a byte is needed for the ASCII code and the other byte is used for the character's attributes discussed later. Now the first 80 words will correspond to the first row of the screen and the next 80 words will correspond to the next row.
- By making the memory on the video controller accessible to the processor via the system bus, the processor is now in control of what is displayed on the screen.
- The three important things that we discussed are.
  - One screen location corresponds to a word in the video memory
  - The video controller memory is accessible to the processor like its own memory.
  - ASCII code of a character placed at a cell in the VGA memory will cause the corresponding ASCII shape to be displayed on the corresponding screen location.

# Display Memory Base Address

- The memory at which the video controller's memory is mapped must be a standard, so that the program can be written in a video card independent manner.
- Otherwise if different vendors map their video memory at different places in the address space, as was the problem in the start, writing software was a headache.
- BIOS vendors had a problem of dealing with various card vendors.
- The IBM PC text mode color display is now fixed so that system software can work uniformly.
- It was fixed at the physical memory location of B8000.
- The first byte at this location contains the ASCII for the character displayed at the top left of the video screen.
- Dropping the zero we can load the rest in a segment register to access the video memory.
- If we do something in this memory, the effect can be seen on the screen. For example we can write a virus that makes any character we write drop to the bottom of the screen.

### Attribute Byte

The second byte in the word designated for one screen location holds the foreground and background colors for the character. This is called its video attribute. So the pair of the ASCII code in one byte and the attribute in the second byte makes the word that corresponds to one location on the screen. The lower address contains the code while the higher one contains the attribute. The attribute byte as detailed below has the RGB for the foreground and the background. It has an intensity bit for the foreground color as well thus making 16 possible colors of the foreground and 8 possible colors for the background. When bit 7 is set the character keeps on blinking on the screen. This bit has some more interpretations like background intensity that has to be activated in the video controller through its I/O ports.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

7 – Blinking of foreground character
6 – Red component of background color
5 – Green component of background color
4 – Blue component of background color
3 – Intensity component of foreground color
2 – Red component of foreground color
1 – Green component of foreground color
0 – Blue component of foreground color

# Attribute Byte

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

7 – Blinking of foreground character
6 – Red component of background color
5 – Green component of background color
4 – Blue component of background color
3 – Intensity component of foreground color
2 – Red component of foreground color
1 – Green component of foreground color
0 – Blue component of foreground color

0 □ Black
Max Color □ White

A

| FG | Background | | | Foreground | | | |
|---|---|---|---|---|---|---|---|
| Blink | R | G | B | Intensity | R | G | B |
| | | | | | | | |

# Attribute Byte

| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|

7 – Blinking of foreground character
6 – Red component of background color
5 – Green component of background color
4 – Blue component of background color
3 – Intensity component of foreground color
2 – Red component of foreground color
1 – Green component of foreground color
0 – Blue component of foreground color

A

| FG | Background | | | Foreground | | | |
|---|---|---|---|---|---|---|---|
| **Blink** | **R** | **G** | **B** | **Intensity** | **R** | **G** | **B** |
| **1** | **0** | **0** | **0** | **1** | **1** | **1** | **1** |

# Display Memory

**□ 80 Columns □**

**□ 25 Rows □**

| | **0** | **1** | **2** | **…** | **j** | **…** | **77** | **78** | **79** |
|---|---|---|---|---|---|---|---|---|---|
| **0** | (0,0) | (0,1) | (0,2) | | | | | | (0,79) |
| **1** | (1,0) | | | | | | | | |
| **2** | (2,0) | | | | | | | | |
| … | | | | | | | | | |
| **…** | | | | | | | | | |
| | | | | | | | | | |
| **i** | | | | | (i, j) | | | | |
| **…** | | | | | | | | | |
| | | | | | | | | | |
| **…** | | | | | | | | | |
| **22** | | | | | | | | | |
| **23** | | | | | | | | | |
| **24** | (24,0) | | | | | | | | (24,79) |

**Display Memory is a 2-D array of 25x80 Cells.**

**We can write one character in each Cell.**

# Display Memory

□ 80 Columns □

□ 25 Rows □

| | 0 | 1 | 2 | … | j | … | 77 | 78 | 79 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | (0,0) | (0,1) | (0,2) | | | | | | (0,79) |
| 1 | (1,0) | | | | | | | | |
| 2 | (2,0) | | | | | | | | |
| … | | | | | | | | | |
| … | | | | | | | | | |
| | | | | | | | | | |
| i | | | | | (i, j) | | | | |
| … | | | | | | | | | |
| | | | | | | | | | |
| … | | | | | | | | | |
| 22 | | | | | | | | | |
| 23 | | | | | | | | | |
| 24 | (24,0) | | | | | | | | (24,79) |

1 Word

**Size of each Cell is 1 Word.**

**So this is an Array of 25 x 80 Words**

**How much maximum space we need to save a character?**

# Display Memory

□ 80 Columns □

□ 25 Rows □

| | 0 | 1 | 2 | … | j | … | 77 | 78 | 79 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | (0,0) | (0,1) | (0,2) | | | | | | (0,79) |
| 1 | (1,0) | | | | | | | | |
| 2 | (2,0) | | | | | | | | |
| … | | | | | | | | | |
| … | | | | | | | | | |
| | | | | | | | | | |
| i | | | | | (i, j) | | | | |
| … | | | | | | | | | |
| | | | | | | | | | |
| … | | | | | | | | | |
| 22 | | | | | | | | | |
| 23 | | | | | | | | | |
| 24 | (24,0) | | | | | | | | (24,79) |

| MSB | LSB |
|---|---|

1 word = 2 Bytes

# Display Memory

□ 80 Columns □

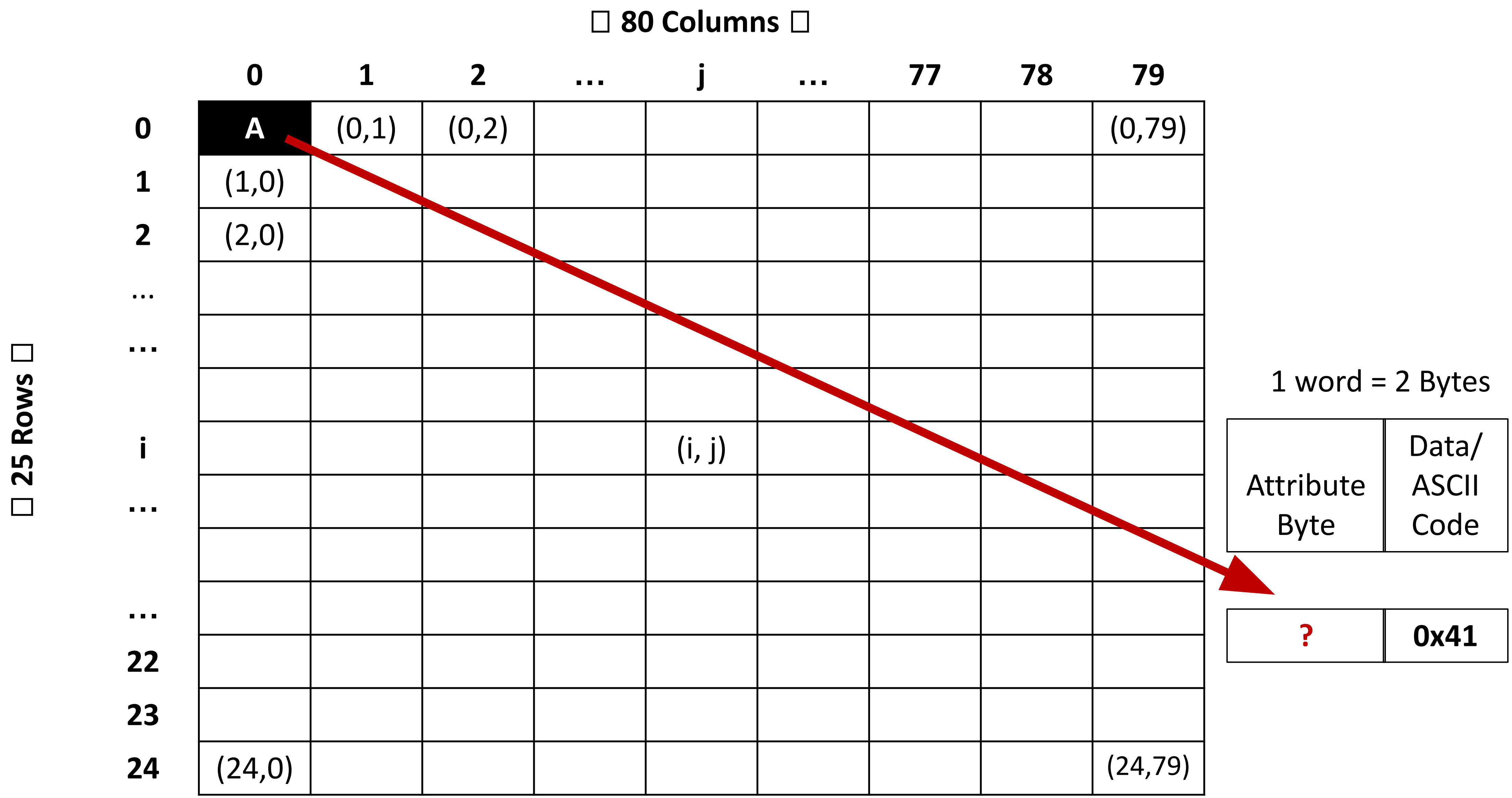
□ 25 Rows □

| | 0 | 1 | 2 | ... | j | ... | 77 | 78 | 79 |
|---|---|---|---|---|---|---|---|---|---|
| **0** | (0,0) | (0,1) | (0,2) | | | | | | (0,79) |
| **1** | (1,0) | | | | | | | | |
| **2** | (2,0) | | | | | | | | |
| ... | | | | | | | | | |
| ... | | | | | | | | | |
| | | | | | | | | | |
| **i** | | | | | (i, j) | | | | |
| ... | | | | | | | | | |
| | | | | | | | | | |
| ... | | | | | | | | | |
| **22** | | | | | | | | | |
| **23** | | | | | | | | | |
| **24** | (24,0) | | | | | | | | (24,79) |

1 word = 2 Bytes

| | |
|---|---|
| Attribute Byte | Data/ ASCII Code |

# Display Memory



# Display Memory

**□ 80 Columns □**

**□ 25 Rows □**

| | **0** | **1** | **2** | **…** | **j** | **…** | **77** | **78** | **79** |
|---|---|---|---|---|---|---|---|---|---|
| **0** | **B8000** | **B8002** | **B8004** | **…** | | | | | X |
| **1** | X+2 | X+4 | X+6 | | | | | | X+160 |
| **2** | | | | | | | | | |
| … | | | | | | | | | |
| **…** | | | | | | | | | |
| | | | | | | | | | |
| **i** | | | | | | | | | |
| **…** | | | | | | | | | |
| | | | | | | | | | |
| **…** | | | | | | | | | |
| **22** | | | | | | | | | |
| **23** | | | | | | | | | |
| **24** | | | | | | | | | |

**Display Memory region starts at Physical Address 0xB8000.**

**Everything that you write at this Memory will be visible on screen.**

# Desired Screen Location (r,c)

□ 80 Columns □

Word No.

Word No.
(80 x r) + c
Byte No.
((80xr)+c)x2

Logical Address:
B800: ((80xr)+c)x2

□ 25 Rows □

| | 0 | 1 | 2 | … | c | … | 77 | 78 | 79 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 2 | … | | | | | 79 |
| 1 | 80x1 | | | | | | | | |
| 2 | 80x2 | | | | | | | | |
| 3 | 80x3 | | | | | | | | |
| … | | | | | | | | | |
| | | | | | | | | | |
| r | 80xr | +1 | +2 | | +c | | | | |
| … | | | | | | | | | |
| | | | | | | | | | |
| … | | | | | | | | | |
| 22 | | | | | | | | | |
| 23 | | | | | | | | | |
| 24 | | | | | | | | | |

### Display Examples

Both DS and ES can be used to access the video memory. However we commonly keep DS for accessing our data, and load ES with the segment of video memory. Loading a segment register with an immediate operand is not allowed in the 8088 architecture. We therefore load the segment register via a general purpose register. Other methods are loading from a memory location and a combination of push and pop.

```
mov  ax, 0xb800
mov  es, ax
```

This operation has opened a window to the video memory. Now the following instruction will print an 'A' on the top left of the screen in white color on black background.

```
mov  word [es:0], 0x0741
```

The segment override is used since ES is pointing to the video memory. Since the first word is written to, the character will appear at the top left of the screen. The 41 that goes in the lower byte is the ASCII code for 'A'. The 07 that goes in the higher byte is the attribute with I=0, R=1, G=1, B=1 for the foreground, meaning white color in low intensity and R=0, G=0, B=0 for the background meaning black color and the most significant bit cleared so that there is no blinking. Now consider the following instruction.

```
mov  word [es:160], 0x1230
```

This is displayed 80 words after the start and there are 80 characters in one screen row. Therefore this is displayed on the first column of the second line. The ASCII code used is 30, which represents a '0' while the attribute byte is 12 meaning green color on blue background.

**Example 6.1**

```
01  ; clear the screen
02  [org 0x0100]
03                mov  ax, 0xb800           ; load video base in ax
04                mov  es, ax               ; point es to video base
05                mov  di, 0                ; point di to top left column
06
07  nextchar:     mov  word [es:di], 0x0720 ; clear next char on screen
08                add  di, 2                ; move to next screen location
09                cmp  di, 4000             ; has the whole screen cleared
10                jne  nextchar             ; if no clear next position
11
12                mov  ax, 0x4c00           ; terminate program
13                int  0x21
```

| | |
|---|---|
| 07 | The code for space is 20 while 07 is the normal attribute of low intensity white on black with no blinking. Even to clear the screen or put a blank on a location there is a numeric code. |
| 08 | DI is incremented twice since each screen location corresponds to two byte in video memory. |
| 09 | DI is compared with 80*25*2=4000. The last word location that corresponds to the screen is 3998. |

Inside the debugger the operation of clearing the screen cannot be observed since the debugger overwrites whatever is displayed on the screen. Directly executing the COM file from the command prompt*, we can see that the screen is cleared. The command prompt that reappeared is printed after the termination of our application. This is the first application that can be directly executed to see some output on the screen.

## 6.3. HELLO WORLD IN ASSEMBLY LANGUAGE

To declare a character in assembly language, we store its ASCII code in a byte. The assembler provides us with another syntax that doesn't forces us to remember the ASCII code. The assembler also provides a syntax that simplifies declaration of consecutive characters, usually called a string. The three ways used below are identical in their meaning.

```
db    0x61, 0x62, 0x63
db    'a', 'b', 'c'
db    'abc'
```

When characters are stored in any high level or low level language the actual thing stored in a byte is their ASCII code. The only thing the language helps in is a simplified declaration.

Traditionally the first program in higher level languages is to print "hello world" on the screen. However due to the highly granular nature of assembly language, we are only now able to write it in assembly language. In writing this program, we make a generic routine that can print any string on the screen.

**Example 6.2**

```
; hello world in assembly
[org 0x0100]
              jmp  start

message:      db   'hello world'        ; string to be printed
length:       dw   11                   ; length of the string

; subroutine to clear the screen
clrscr:       push es
              push ax
              push di

              mov  ax, 0xb800
              mov  es, ax               ; point es to video base
              mov  di, 0                ; point di to top left column

nextloc:      mov  word [es:di], 0x0720 ; clear next char on screen
              add  di, 2                ; move to next screen location
              cmp  di, 4000             ; has the whole screen cleared
              jne  nextloc              ; if no clear next position

              pop  di
              pop  ax
              pop  es
              ret

```

```
; subroutine to print a string at top left of screen
; takes address of string and its length as parameters
printstr:     push bp
              mov  bp, sp
              push es
              push ax
              push cx
              push si
              push di

              mov  ax, 0xb800
              mov  es, ax               ; point es to video base
              mov  di, 0                ; point di to top left column
              mov  si, [bp+6]           ; point si to string
              mov  cx, [bp+4]           ; load length of string in cx
              mov  ah, 0x07             ; normal attribute fixed in al

nextchar:     mov  al, [si]             ; load next char of string
              mov  [es:di], ax          ; show this char on screen
              add  di, 2                ; move to next screen location
              add  si, 1                ; move to next char in string
              loop nextchar             ; repeat the operation cx times

              pop  di
              pop  si
              pop  cx
              pop  ax
              pop  es
              pop  bp
              ret  4

start:        call clrscr               ; call the clrscr subroutine

              mov  ax, message
              push ax                   ; push address of message
              push word [length]        ; push message length
              call printstr             ; call the printstr subroutine

              mov  ax, 0x4c00           ; terminate program
              int  0x21
```

| | |
|---|---|
| 05-06 | The string definition syntax discussed above is used to declare a string "hello world" of 11 bytes and the length is stored in a separate variable. |
| 09-25 | The code to clear the screen from the last example is written in the form of a subroutine. Since the subroutine had no parameters, only modified registers are saved and restored from the stack. |
| 29-35 | The standard subroutine format with parameters received via stack and all registers saved and restored is used. |
| 37-42 | ES is initialized to point to the video memory via the AX register. Two pointer registers are used; SI to point to the string and DI to point to the top left location of the screen. CX is loaded with the length of the string. Normal attribute of low intensity white on black with no blinking is loaded in the AH register. |
| 44-45 | The next character from the string is loaded into AL. Now AH holds the attribute and AL the ASCII code of the character. This pair is written on the video memory using DI with the segment override prefix for ES to access the video memory segment. |
| 46-47 | The string pointer is incremented by one while the video memory pointer is incremented by two since one char corresponds to a word on the screen. |
| 48 | The loop instruction used is equivalent to a combination of "dec cx" and "jnz nextchar." The loop is executed CX times. |
| 50-56 | The registers pushed on the stack are recovered in opposite order and the "ret 4" instruction removes the two parameters placed on the stack. |
| 62 | Memory can be directly pushed on the stack. |

# Number Printing in Assembly

- Another problem related to the display is printing numbers.
- Every high level language allows some simple way to print numbers on the screen.
- As we have seen, everything on the screen is a pair of ASCII code and its attribute and a number is a raw binary number and not a collection of ASCII codes.
- For example a 10 is stored as a 10 and not as the ASCII code of 1 followed by the ASCII code of 0.
- If this 10 is stored in a screen location, the output will be meaningless, as the character associate to ASCII code 10 will be shown on the screen.
- So there is a process that converts a number in its ASCII representation.
- This process works for any number in any base. We will discuss our examples with respect to the decimal base and later observe the effect of changing to different bases.

# Number Printing Algorithm

- The key idea is to divide the number by the base number, 10 in the case of decimal. The remainder can be from 0-9 and is the right most digit of the original number. The remaining digits fall in the quotient. The remainder can be easily converted into its ASCII equivalent and printed on the screen. The other digits can be printed in a similar manner by dividing the quotient again by 10 to separate the next digit and so on.
- However the problem with this approach is that the first digit printed is the right most one. For example 253 will be printed as 352. The remainder after first division was 3, after second division was 5 and after the third division was 2. We have to somehow correct the order so that the actual number 253 is displayed, and the trick is to use the stack since the stack is a Last In First Out structure so if 3, 5, and 2 are pushed on it, 2, 5, and 3 will come out in this order. The steps of our algorithm are outlined below.
    - Divide the number by base (10 in case of decimal)
    - The remainder is its right most digit
    - Convert the digit to its ASCII representation (Add 0x30 to the remainder in case of decimal)
    - Save this digit on stack
    - If the quotient is non-zero repeat the whole process to get the next digit, otherwise stop
    - Pop digits one by one and print on screen left to right

# DIV Instruction

- The division used in the process is integer division and not floating point division.
- Integer division gives an integer quotient and an integer remainder.
- A division algorithm is now needed. Fortunately or unfortunately there is a DIV instruction available in the 8088 processor.
- There are two forms of the DIV instruction. The first form divides a 32bit number in DX:AX by its 16bit operand and stores the 16bit quotient in AX and the 16bit remainder in DX. The second form divides a 16bit number in AX by its 8bit operand and stores the 8bit quotient in AL and the 8bit remainder in AH.
- For example “DIV BL” has an 8bit operand, so the implied dividend is 16bit and is stored in the AX register and “DIV BX” has a 16bit operand, so the implied dividend is 32bit and is therefore stored in the  concatenation of the DX and AX registers. The higher word is stored in DX and the lower word in AX.

# DIV Instruction

- If a large number is divided by a very small number it is possible that the quotient is larger than the space provided for it in the implied destination. In this case an interrupt is automatically generated and the program is usually terminated as a result. This is called a divide overflow error; just like the calculator shows an –E– when the result cannot be displayed. This interrupt will be discussed later in the discussion of interrupts.
- DIV (divide) performs an unsigned division of the accumulator (and its extension) by the source operand. If the source operand is a byte, it is divided into the two-byte dividend assumed to be in registers AL and AH. The byte quotient is returned in AL, and the byte remainder is returned in AH. If the source operand is a word, it is divided into the two-word dividend in registers AX and DX. The word quotient is returned in AX, and the word remainder is returned in DX. If the quotient exceeds the capacity of its destination register (FF for byte source, FFFF for word source), as when division by zero is attempted, a type 0 interrupt is generated, and the quotient and remainder are undefined.

Nun

**Example 6.3**

```
; number printing algorithm
[org 0x0100]
              jmp  start

;;;;; COPY LINES 008-025 FROM EXAMPLE 6.2 (clrscr) ;;;;;

; subroutine to print a number at top left of screen
; takes the number to be printed as its parameter
printnum:     push bp
              mov  bp, sp
              push es
              push ax
              push bx
              push cx
              push dx
              push di

              mov  ax, 0xb800
              mov  es, ax              ; point es to video base
              mov  ax, [bp+4]          ; load number in ax
              mov  bx, 10              ; use base 10 for division
              mov  cx, 0               ; initialize count of digits

nextdigit:    mov  dx, 0               ; zero upper half of dividend
              div  bx                  ; divide by 10
              add  dl, 0x30            ; convert digit into ascii value
              push dx                  ; save ascii value on stack
              inc  cx                  ; increment count of values
              cmp  ax, 0               ; is the quotient zero
              jnz  nextdigit           ; if no divide it again

              mov  di, 0               ; point di to top left column

```

```
nextpos:        pop  dx                 ; remove a digit from the stack
                mov  dh, 0x07           ; use normal attribute
                mov [es:di], dx         ; print char on screen
                add  di, 2              ; move to next screen location
                loop nextpos            ; repeat for all digits on stack

                pop  di
                pop  dx
                pop  cx
                pop  bx
                pop  ax
                pop  es
                pop  bp
                ret  2

start:          call  clrscr            ; call the clrscr subroutine

                mov ax, 4529
                push ax                 ; place number on stack
                call printnum           ; call the printnum subroutine

                mov ax, 0x4c00          ; terminate program
                int 0x21
```

| | |
|---|---|
| 026-033 | The registers are saved as an essential practice. The only parameter received is the number to be printed. |
| 035-039 | ES is initialized to video memory. AX holds the number to be printed. BX is the desired base, and can be loaded from a parameter. CX holds the number of digits pushed on the stack. This count is initialized to zero, incremented with every digit pushed and is used when the digits are popped one by one. |
| 041-042 | DX must be zeroed as our dividend is in AX and we want a 32bit division. After the division AX holds the quotient and DX holds the remainder. Actually the remainder is only in DL since the remainder can be from 0 to 9. |
| 043-045 | The remainder is converted into its ASCII representation and saved on the stack. The count of digits on the stack is incremented as well. |
| 046-047 | If the quotient is zero, all digits have been saved on the stack and if it is non-zero, we have to repeat the process to print the next digit. |
| 049 | DI is initialized to point to the top left of the screen, called the cursor home. If the screen location is to become a parameter, the value loaded in DI will change. |
| 051-053 | A digit is popped off the stack, the attribute byte is appended to it and it is displayed on the screen. |
| 054-055 | The next screen location is two bytes ahead so DI is incremented by two. The process is repeated CX times which holds the number of digits pushed on the stack. |
| 057-064 | We pop the registers pushed and "ret 2" to discard the only parameter on the stack. |
| 066-070 | The main program clears the screen and calls the printnum subroutine to print 4529 on the top left of the screen. |

- When the program is executed 4529 is printed on the top left of the screen.
- This algorithm is versatile in that the base number can be changed and the printing will be in the desired base.
- For example if "mov bx, 10" is changed to "mov bx, 2" the output will be in binary as 0010001101100001.
- Similarly changing it to "mov bx, 8" outputs the number in octal as 10661.
- Printing it in hexadecimal is a bit tricky, as the ASCII codes for A-F do not consecutively start after the codes for 0-9.
- Inside the debugger observe the working of the algorithm is just as described in the above illustration. The digits are separated one by one and saved on the stack.
- From bottom to top, the stack holds 0034, 0035, 0032, and 0039 after the first loop is completed.
- The next loop pops them one by one and routes them to the screen.

## 6.5. SCREEN LOCATION CALCULATION

Until now our algorithms used a fixed attribute and displayed at a fixed screen location. We will change that to use any position on the screen and any attribute. For mapping from the two dimensional coordinate system of the screen to the one dimensional memory, we need to multiply the row number by 80 since there are 80 columns per row and add the column number to it and again multiply by two since there are 2 bytes for each character.

For this purpose the multiplication routine written previously can be used. However we introduce an instruction of the 8088 microprocessor at this time that can multiply 8bit or 16bit numbers.

### MUL Instruction

MUL (multiply) performs an unsigned multiplication of the source operand and the accumulator. If the source operand is a byte, then it is multiplied by register AL and the double-length result is returned in AH and AL. If the source operand is a word, then it is multiplied by register AX, and the double-length result is returned in registers DX and AX.

### String Printing at Desired Location

We modify the string printing program to take the x-position, the y-position, and the attribute as parameters. The desired location on the screen can be calculated with the following formulae.

```
location = ( hypos * 80 + epos ) * 2
```

### Example 6.4

```
; hello world at desired screen location
[org 0x0100]
              jmp  start

message:      db   'hello world'      ; string to be printed
length:       dw   11                 ; length of the string

;;;;; COPY LINES 008-025 FROM EXAMPLE 6.2 (clrscr) ;;;;;

; subroutine to print a string at top left of screen
; takes x position, y position, string attribute, address of string
; and its length as parameters
printstr:     push bp
              mov  bp, sp
              push es
              push ax
              push cx
              push si
              push di

              mov  ax, 0xb800
              mov  es, ax             ; point es to video base
              mov  al, 80             ; load al with columns per row
              mull  byte [bp+10]       ; multiply with y position
              add  ax, [bp+12]        ; add x position
              shl  ax, 1              ; turn into byte offset
              mov  dial              ; point di to required location
              mov  si, [bp+6]         ; point si to string
              mov  cx, [bp+4]         ; load length of string in cx
              mov  ah, [bp+8]         ; load attribute in ah

nextchar:     mov  al, [si]           ; load next char of string
              mov  [es:di], ax        ; show this char on screen
              add  di, 2              ; move to next screen location
```

```
            add  si, 1                  ; move to next char in string
            loop nextchar               ; repeat the operation cx times

            pop  di
            pop  si
            pop  cx
            pop  ax
            pop  es
            pop  bp
            ret  10

start:      call clrscr                 ; call the clrscr subroutine

            mov  ax, 30
            push ax                     ; push x position
            mov  ax, 20
            push ax                     ; push y position
            mov  ax, 1                  ; blue on black attribute
            push ax                     ; push attribute
            mov  ax, message
            push ax                     ; push address of message
            push word [length]          ; push message length
            call printstr               ; call the printstr subroutine

            mov  ax, 0x4c00             ; terminate program
            int  0x21
```

| | |
|---|---|
| 41 | Push and pop operations always operate on words; however data can be read as a word or as a byte. For example we read the lower byte of the parameter y-position in this case. |
| 43 | Shifting is used for multiplication by two, which should always be the case when multiplication or division by a power of two is desired. |
| 61 | The subroutine had 5 parameters so “ret 10” is used. |
| 65-74 | The main program pushes 30 as x-position, 20 as y-position meaning 30th column on 20th row. It pushes 1 as the attribute meaning low intensity blue on black with no blinking. |

- When the program is executed hello world is displayed at the desired screen location in the desired color.
- The x-position, y-position, and attribute parameters can be changed and their effect be seen on the screen.
- The important difference in this example is the use of MUL instruction and the calculation of screen location given the x and y positions.

# Acknowledgements


- Some of the slides are adopted from Ms. Samin Iftikhar’s and  Mr. Belal Hashmi’s lecture notes.