The x86 PC

assembly language, design, and interfacing

fifth edition

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VIDEO AND VIDEO ADAPTERS

The x86 PC

assembly language, design, and interfacing

fifth edition

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OBJECTIVES

this chapter enables the student to:

- Determine the quality of a monitor by technical features such as resolution, dot rate, horizontal and vertical frequency, and dot pitch.
- Describe how images are produced on the screen by the method called raster scanning.
- Explain the function of the video adapter board and its two components:
  - Video display RAM and the video controller.
- Describe the differences in text and graphics modes.

OBJECTIVES
this chapter enables the student to: (*cont*)

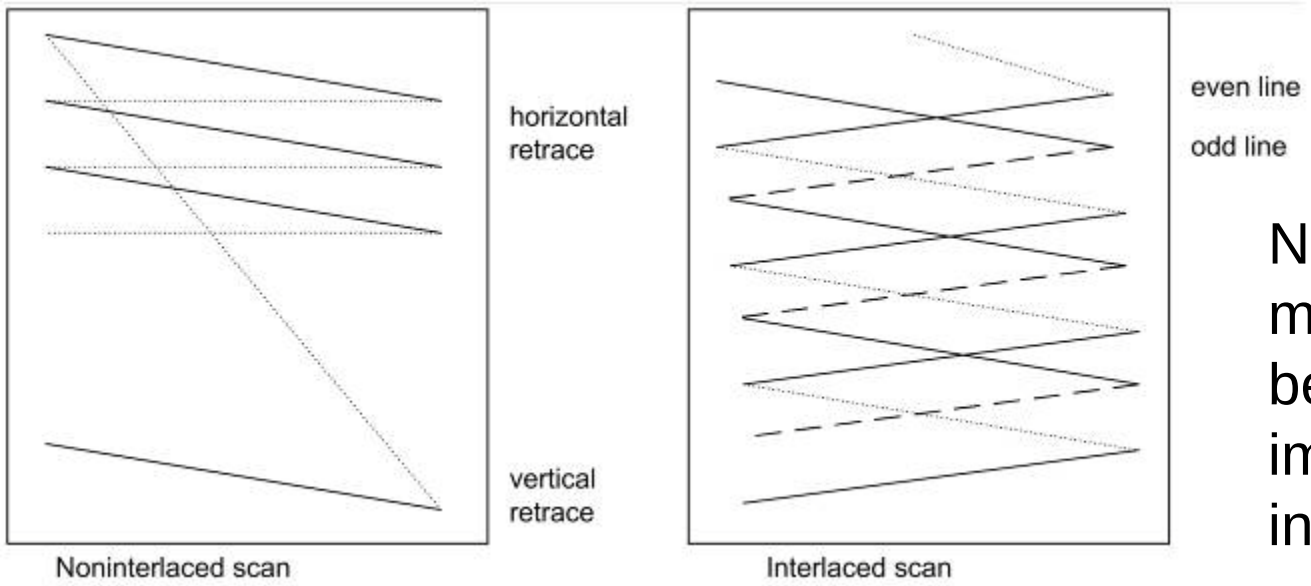
- State the purpose of the attribute byte and how it affects storage space in video display RAM.
- Write Assembly language programs to manipulate text data on the screen using INT 10H.
- Describe the relation between the number of colors available for a monitor and the amount of video memory needed.
- Write an Assembly language program to program pixels on the screen.

16.1: MONITORS & VIDEO MODES

- Video monitors use a method called raster scanning to display images on the monitor screen.
  - A beam of electrons illumine phosphorus dots, called pixels, on the screen.
  - This electron gun *rasters* from the top left corner of the screen to the bottom right, one line at a time.
  - As the gun turns on and off, it moves from left to right toward the end of the line.
    - Turning off & moving to the next line is called *horizontal retrace*.
  - When it reaches the bottom right of the screen, the gun is turned off and moves to the top left of the screen.
    - Turning off &moving back to the top is called *vertical retrace*.

16.1: MONITORS & VIDEO MODES

- Shown are two methods of scanning: noninterlaced (normal) scanning & interlaced scanning.
  - In interlaced scanning, each frame is scanned twice.
    - Odd lines are scanned, then the gun scans even lines.



Non-interlaced monitors provide better flicker-free images than do interlaced monitors.

Fig. 16-1 CRT Scanning Methods

16.1: MONITORS & VIDEO MODES
how to judge a monitor

- Screen resolution depends upon the following:
  - 1. The number of pixels (dots) per scanned line
  - 2. The speed at which the gun can turn on & off phosphors on the surface of the tube
  - 3. Speed at which it can scan & retrace a horizontal line.
  - 4. The number of scan lines per screen (frame)
  - 5. The speed at which it finishes one frame and performs

16.1: MONITORS & VIDEO MODES
how to judge a monitor

- In a television set, horizontal scanning is done at 15,750 times per second (15.75 kHz), and vertical scanning at 60 times per second (60 Hz)
  - The PC monochrome monitor and display adapter (MDA) frequencies are 18.432 kHz and 50 Hz.
- The three most critical factors in a monitor are:
  - 1. The video frequency.
    (dot rate, pixel rate, or video bandwidth)
  - 2. The horizontal frequency.
  - 3. The vertical frequency.

16.1: MONITORS & VIDEO MODES
how to judge a monitor

- Calculate the maximum number of scan lines per screen by dividing the horizontal frequency by the vertical frequency:

number of scanned lines per screen = horizontal freq. (HF) / vertical freq. (VF)
(not all visible)

Example 16-1

In a IBM PC monochrome monitor with HF = 18.432 kHz and VF = 50 Hz, calculate the number of scanned lines per screen.

Solution:

The number of scanned lines = HF/VF; therefore, 18,432 divided by 50 = 368 lines per screen.

16.1: MONITORS & VIDEO MODES
how to judge a monitor

- The number of pixels (dots) are there per line is calculated by dividing the video frequency (dot frequency) by the horizontal frequency:

number of pixels per scan line = dot frequency / horizontal frequency
(not all visible)

Example 16-2

A manufacturer has advertised a 14-inch monitor of 1024 × 768 resolution with a dot pitch of 0.28. Calculate the diagonal size of the image on the screen. It must be less than 14 inches.

Solution:

The calculation is as follows:

$(\text{diagonal size})^2 = (1024 \times 0.28 \text{ mm})^2 + (768 \times 0.28 \text{ mm})^2$

diagonal size (inches) = 358 mm × 0.039 inch per mm = 13.99 inches

16.1: MONITORS & VIDEO MODES
dot pitch

- Dot pitch is the distance between adjacent pixels (dots) given in millimeters.
  - The smaller the pixel size & the smaller the space between them, the higher total number of pixels and the better the resolution.
    - Dot pitch varies from 0.6 inch to 0.2 inch.
- Monitors, like televisions, are advertised according to their diagonal size, with a relation between:
  - The number of horizontal and vertical pixels.
  - The dot pitch
  - The diagonal size of the image on the screen. (always less than the monitor's diagonal size)

16.1: MONITORS & VIDEO MODES
phosphors

- Brightness of the pixels depends on two factors:
  - Intensity of the electron beam, which decides how bright or dark each pixel should be.
  - Phosphor material used—some phosphor materials retain their brightness for longer periods than others.
    - Called *persistence*, fixed in the monitor, and cannot be changed.

16.1: MONITORS & VIDEO MODES
color monitors

- In color monitors every phosphor dot is made of three colors: **red**, **green**, and **blue**.
  - Hence the name **RGB** (**red**/**green** / **blue**) monitors.
- Color monitors require three different wires to carry three electronic beams, one for each color.
  - Unless the monitor is a composite with one single wire that carries all three colors.

16.1: MONITORS & VIDEO MODES
color monitors

- Another difference is the presence of the shadow mask on color monitors.
  - A metal plate with many holes placed just before the phosphor-coated screen to coordinate shooting of the electron beam of each gun through a single hole.
- The dot pitch on color monitors is the distance between two dots of the same color.
  - Or, the distance between two consecutive holes of the shadow mask.
- In color monitors, the combination of the three primary colors generates all other colors.

16.1: MONITORS & VIDEO MODES
analog and digital monitors

- Digital monitors, such as the MDA- and CGA-based monitors, use a number of bits to specify variations of color and intensity.
  - To increase these variations employs large numbers of bits.
- Analog monitors, which accommodate many more variations, have much better quality pictures.

16.1: MONITORS & VIDEO MODES
video display RAM and video controller

- Communication between the system board & video display monitor is through the *video adapter* board.
  - Every video board must have a video controller and video display RAM.
- Information displayed on the monitor is stored in memory called video display RAM (VDR).
  - Also called the video buffer.
- The video controller's sole job is to take care of the video section of the computer.
  - Video RAM must be accessible to both the main processor and the video processor.

16.1: MONITORS & VIDEO MODES
video display RAM and video controller

- In the PC, 128K bytes of the 1 megabyte of addressable memory, from address A0000H to BFFFFH, is set aside for video display RAM.
  - IBM monochrome adapter uses 4K, starting at B0000H.
    - 2K bytes are for the full screen of characters (80 characters per line and 25 lines per screen = 2000 bytes)
    - 2K for the attributes such as color, intensity, and blinking.

16.1: MONITORS & VIDEO MODES
video display RAM and video controller

- There are several solutions to the dilemma presented by the same video display RAM being accessed by both the microprocessor and the video controller
  - 1. The CPU can access the video RAM only during the time when the video controller is doing the retrace.
  - 2. Use a more expensive, specially designed kind of RAM called VRAM (video RAM).
  - 3. Use dual-port RAMs, which feature two sets of data pins, allowing both CPU & video controller to access video RAM with much less conflict.

16.1: MONITORS & VIDEO MODES
character box

- Video boards can be programmed in two modes.
  - **Text mode** - characters, which are a group of pixels, are accessed,
  - **Graphics mode** - individual pixels are accessed and manipulated, in text mode characters, which are a group of pixels, are accessed.

16.1: MONITORS & VIDEO MODES
character box

- In text mode, horizontal and vertical pixels are grouped into *character boxes*, which can display a single character.
  - The size of the character box matrix varies.
    - IBM's MDA (monochrome display adapter) has a 9 pixel by 14 pixel character box.

Example 16-3

If the MDA character box is 9 × 14 (9 pixels wide and 14 pixels high) and the resolution of MDA is 720 × 350, verify the fact that MDA in text mode can display 80 × 25 characters per screen.

Solution:

720 horizontal scan lines divided by 9, the width of character box, gives 80 columns of characters. Dividing 350 vertical pixels by 14, the height of the character box, results in 25 rows of characters.

16.1: MONITORS & VIDEO MODES
character box

- Horizontal & vertical pixels are calculated the using the size of the character box, the number of rows, and the number of columns per screen:

pixels per scan line = number of character columns × pixel width of char. box
raster lines = number of rows per screen × pixel height of char. box

Example 16-4

In a given adapter, the character box is 8 × 14 and the adapter in text mode displays 80 × 25 characters. Calculate the pixel resolution.

Solution:

The total number of horizontal pixels is 640 (8 × 80) and the vertical number is 350 (14 × 25). Therefore, it has 640 × 350 resolution.

16.1: MONITORS & VIDEO MODES
character box

- The number of horizontal & vertical pixels is directly proportional to horizontal & vertical dot frequencies.
  - In judging CRT monitors, look for higher HF (horizontal frequency), VF (vertical frequency), and DF (dot frequency).

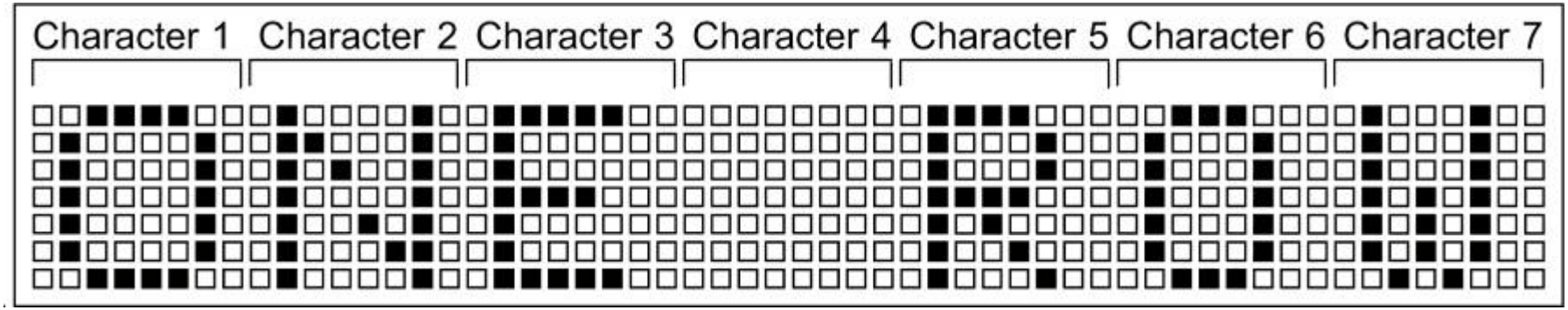


Fig. 16-2 Character Boxes

16.1: MONITORS & VIDEO MODES
x86 PC video modes

- The PC was introduced in 1981 with two video monitor options: MDA (monochrome display adapter) and CGA (color graphics adapter).
- EGA (enhanced graphics adapter) was introduced in 1985 to provide graphics & text on the same monitor.

16.1: MONITORS & VIDEO MODES
x86 PC video modes

- In 1987, IBM introduced VGA (video graphics adapter) and MCGA (multicolor graphics array).
- In today's PC, VGA is already on the motherboard.
  - Adapter boards are available for high-performance video games to be plugged into an x86 the expansion slot.

D7	D6	D5	D4	D3	D2	D1	D0
B	R	G	B	I	R	G	B
	Background			Foreground			

B = blinking, I = intensity
Both blinking and intensity are applied to foreground only .

16.1: MONITORS & VIDEO MODES
x86 PC video modes

- Currently, some manufacturers make high-performance VGA-compatible adapter plug-in boards for graphic-intensive video games.

Table 16-1. Adapter Characteristics

Adapter	Year Intro.	Dot Rate MHz	Horizontal Rate kHz	Vertical Rate Hz	Monitor Type
CGA	1981	14.318	15.75	60	COMP. dig. RGB
MDA	1981	16.257	18.43	50	Digital mono
EGA	1984	14.318	15.75	60	Digital RGB
		16.257	18.43	50	Digital mono
		16.257	21.85	60	Digital RGB
VGA	1987	25.175	31.5	70	Analog
		28.175	31.5	70	Analog
		25.175	31.5	70	Analog
		25.175	31.5	60	Analog

16.1: MONITORS & VIDEO MODES
x86 PC video modes

- VGA emulates all modes of CGA, MDA, and EGA, plus some new modes not available in earlier adapters.
  - Fig. 16-3 on page 431 shows the various color modes available in text mode.
  - Fig. 16-4 on page 432 shows the text mode attributes in black and white.

Table 16-2: 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

16.1: MONITORS & VIDEO MODES
x86 PC video modes

Example 16-5

Using Figure 16-3, find the attribute byte (in binary and hex) for the following color options:

(a) blue on black (b) green on blue (c) high-intensity white on blue
(d) red on blue

Solution:

	Binary	Hex	Color Effect
(a)	0000 0001	01	Blue on black
(b)	0001 0010	12	Green on blue
(c)	0001 1111	1F	High-intensity white on blue
(d)	0001 0100	14	Red on blue

16.1: MONITORS & VIDEO MODES
x86 PC video modes

Example 16-6

Find the attributes associated with the following attribute bytes in MDA.
(a) 07H (b) 0FH (c) 70H

Solution:

(a) 07H = 00000111 gives background black, foreground normal intensity, nonblinking.
(b) 0FH = 00001111 gives the same as (a) except with foreground highlighted.
(c) 70H = 01110000 gives black on white, a reverse video screen mode in which the foreground is black and the background is white, nonblinking.

16.1: MONITORS & VIDEO MODES
video memory and attributes in VGA

- Up to 1M of DRAM can be installed on VGA boards.
  - Extra memory is used to store pixels and their attributes.
- VGA can display 256 colors out of 262,144 possible.
  - It requires 1 megabyte of DRAM to store them.
- When VGA is programmed to emulate CGA text, the address for the video is B8000H.
  - For MDA emulation the address is B0000H.
  - When VGA is in text mode it uses mode 3.
  - Regardless of mode selected, MDA, CGA, EGA, and MCGA all are supported by the VGA monitor.
    - Examples 16-7 & 16-8 shows use of INT 10H functions.

16.2: TEXT MODE PROGRAMMING & VIDEO RAM
finding the current video mode

- BIOS INT 10H can be used to program x86 video modes using Assembly language instructions.
- To find the current video mode…
  - Set AH = 0F, and use INT 10H as follows:

```
MOV    AH,0FH ;AH=0F
INT    10H
```

16.2: TEXT MODE PROGRAMMING & VIDEO RAM changing the video mode with INT 10H

- To change the video mode...
  - AH = 00 and **AL** = video mode.

Table 16-3: Video Modes and Their Definitions * Color burst off.

AL	Pixels	Chars	Box	T/G	Colors	Mode	Buf	Start
00H	320 × 200	40 × 25	8 × 8	Text	16*	CGA	8	B8000h
	320 × 350	40 × 25	8 × 14	Text	16*	EGA	8	B8000h
	360 × 400	40 × 25	9 × 16	Text	16*	VGA	8	B8000h
	320 × 400	40 × 25	8 × 16	Text	16*	MCG	8	B8000h
01H	320 × 200	40 × 25	8 × 8	Text	16	CGA	8	B8000h
	320 × 350	40 × 25	8 × 14	Text	16	EGA	8	B8000h
	360 × 400	40 × 25	9 × 16	Text	16	VGA	8	B8000h
	320 × 400	40 × 25	8 × 16	Text	16	MCGA	8	B8000h
02H	640 × 200	80 × 25	8 × 8	Text	16*	CGA	8	B8000h

See the entire table on page 431 of your textbook.

16.2: TEXT MODE PROGRAMMING & VIDEO RAM changing the video mode with INT 10H

- Setting the cursor position…
  - AH = 2, DH = row, and DL = column.
  - The following sets the cursor to row 12, column 28:

```
MOV    AH,02 ;set the cursor
MOV    BH,0          ;page 0
MOV    DH,12         ;row 12
MOV    DL,28         ;col 28
INT    10H    ;invoke interrupt
```

16.2: TEXT MODE PROGRAMMING & VIDEO RAM changing the video mode with INT 10H

- Getting the current cursor position…
  - Use AH = 03 of INT 10H.

```
MOV    AH,03 ;get cursor position
MOV    BH,0  ;page 0
INT    10H
```

  - After running the code, registers DH & DL have the row and column positions of the cursor (in hex).

16.2: TEXT MODE PROGRAMMING & VIDEO RAM changing the video mode with INT 10H

- Scrolling the window up to clear the screen…
  - AH = 06; options 06 & 07 are called scroll functions.

```
MOV    AH,06     ;scroll up option
MOV    AL,0      ;the entire screen
MOV    BH,07     ;normal attribute
MOV    CL,0      ;col 0 (top left col)
MOV    CH,0      ;row 0 (top left row)
MOV    DL,79     ;col 79 (bottom right col)
MOV    DH,24     ;row 24 (bottom right row)
INT    10H
```

  - A more efficient version of the above code is:

```
MOV    AX,0600H
MOV    BH,07
MOV    CX,0
MOV    DX,184FH ;18H=24 AND 4FH=79
INT    10H
```

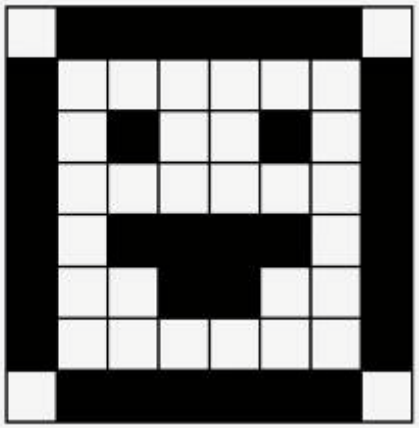
16.2: TEXT MODE PROGRAMMING & VIDEO RAM character generator ROM

- To display characters on the screen, every video board must have access to the pixel patterns of the characters.
  - In CGA, the patterns are burned into BIOS ROM starting at F000:FA60H.

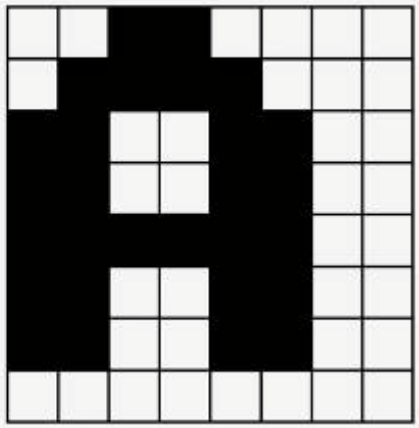
16.2: TEXT MODE PROGRAMMING & VIDEO RAM character generator ROM

- To decipher the patterns, first remember that the CGA character box is 8 x 8.
  - For every ASCII character there must be 64 (8 x 8 = 64) bits for each pattern.
  - Every 8 bytes of the ROM provides the pattern for one character.

Hex	Binary
7E	01111110
81	10000001
A5	10100101
81	10000001
BD	10111101
99	10011001
81	10000001
7E	01111110



Hex	Binary
30	00110000
78	01111000
CC	11001100
CC	11001100
FC	11111100
CC	11001100
CC	11001100
00	00000000



16.2: TEXT MODE PROGRAMMING & VIDEO RAM how characters are displayed in text mode

- The process of generating CGA signals is exactly the same as in MDA, except the video circuitry generates **R** (**red**), **B** (**blue**), **G** (**green**).
  - And vertical, horizontal, intensity, and dot pattern signals.

16.2: TEXT MODE PROGRAMMING & VIDEO RAM how characters are displayed in text mode

- To display characters, the x86 CPU writes the characters and their attributes into the video RAM.
  - Access to the video RAM by both the CPU and the 6845 CRT controller is by use of a multiplexer.
  - The controller fetches characters, sending them to the character generator ROM to get the patterns of every character on each row for the scan lines.
    - Character generator ROM has patterns for all the ASCII characters.
- RA0–RA4 (row address) output pins from 6845 fetch the specific row of the character and send it to a parallel-in-serial-out register. (a *serializer)*

16.2: TEXT MODE PROGRAMMING & VIDEO RAM
character definition table in VGA

- In VGA, the character box is 8 x 16 and the patterns for all the characters are stored in ROM memory.
  - The memory address varies between computers.
- For the address of the character definition table:
  - INT 10H with AH = 11H, AL = 30H, and BH = 06.
    - On return from INT 10H, **ES:BP** has the address.
  - The number of bytes used to form patterns for each character is given in CX.
    - DL has the row number minus one.

16.2: TEXT MODE PROGRAMMING & VIDEO RAM
character definition table in VGA

Example 16-10

Draw the patterns for VGA characters of happy face (02H) and letter "A" (41H) on a 9 × 16 box. Contrast this with CGA in Example 16-9.

Solution:

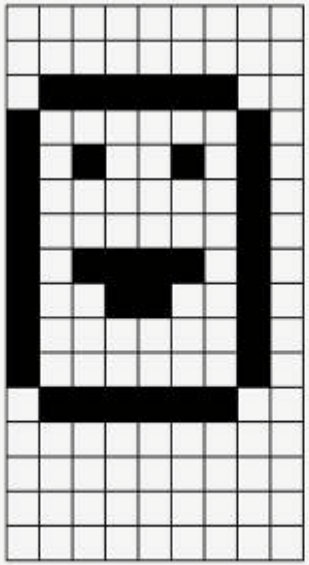
The patterns for these characters are as follows. See Example 16-13 for how to get the patterns. Figure 16-7 shows the diagram.

00,00,7E,81,A5,81,81,BD,99,81,81,7E,00,00,00,00 happy face

00,00,10,38,6C,C6,C6,FE,C6,C6,C6,C6,00,00,00,00 A

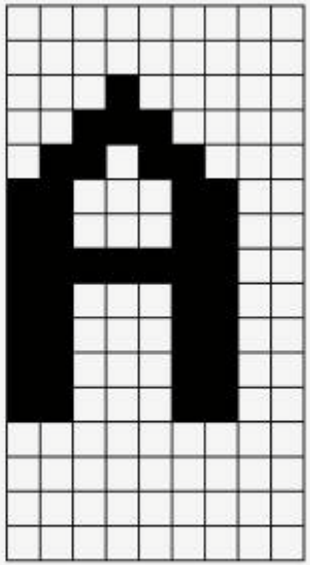
Hex

00
00
7E
81
A5
81
81
BD
99
81
81
7E
00
00
00
00



Hex

00
00
10
38
6C
C6
C6
FE
C6
C6
C6
C6
00
00
00
00



Two characters for VGA.

16.3: GRAPHICS AND GRAPHICS PROGRAMMING
pixel resolution, color & video memory

- In graphics mode, pixel accessing is also referred to as *bit-mapped graphics*.
- There are two facts associated with every pixel on the screen which must be stored in the video RAM:
  - 1. The location of the pixel
  - 2. Its attributes: color and intensity
- Memory requirement goes up as the resolution and the number of colors supported go up.
  - The number of colors displayed at one time is always 2^n where n is the number of bits set aside for the color.

16.3: GRAPHICS AND GRAPHICS PROGRAMMING
pixel resolution, color & video memory

- When 4 bits are assigned for the color of the pixel, this allows 16 combinations of colors to be displayed at one time
  - Because $2^4 = 16$.

Example 16-12

In certain video graphics, a maximum of 256 colors can be displayed at one time. How many bits are set aside for the color of the pixels?

Solution:

To display 256 colors at once, we must have 8 bits set for color since $2^8 = 256$.

16.3: GRAPHICS AND GRAPHICS PROGRAMMING the case of CGA

- The CGA board can have a maximum of 16K bytes.
  - This 16K can hold up to 4 pages of data, where each page represents one full screen of 80 × 25 characters.
- In graphics mode, the number of colors supported varies depending on the resolution, as shown:

320 x 200 (Medium resolution
A total of 64,000 pixels
(320 col x 200 rows = 64,000)

640 x 200 (High resolution
A total of 128,000 pixels
(200 x 640 = 128,000).

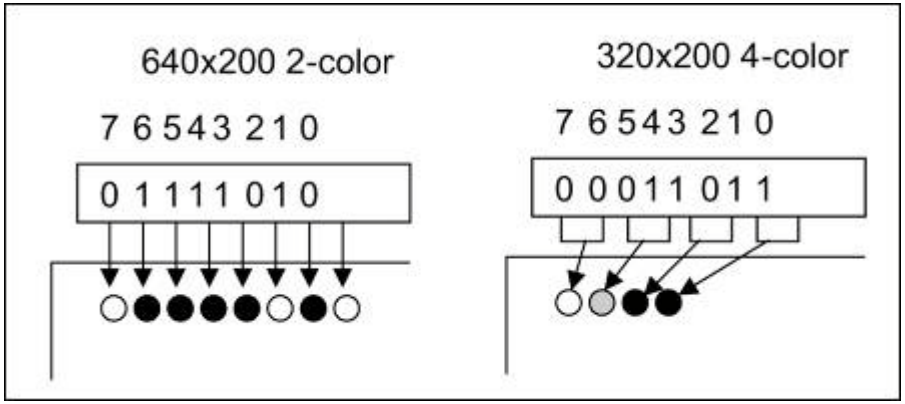


Fig. 16-8 CGA Pixel Mapping

16.3: GRAPHICS AND GRAPHICS PROGRAMMING the case of EGA

- In the EGA board, the memory buffer was increased to a maximum of 256K bytes.
  - Up to 64 colors, however, only 16 can be displayed on the screen at a time.
- EGA graphics memory starts at A0000H, and goes to a maximum of AFFFFH. (256K)
  - IBM designers used four parallel planes, each 64K, to access the entire 256K bytes of video RAM.
    - Each plane holds one bit of the 4-bit color.
- EGA card, IBM introduced palette registers.
  - A total of sixteen 8-bit palette registers.

16.3: GRAPHICS AND GRAPHICS PROGRAMMING the case of VGA

- VGA increased pixels to 640 x 480, with support for 256 colors displayed at one time.
  - The color palette was increased to 2^{18} = 262,144 hues.
  - The number of palette registers was increased to 256.
  - Each palette register holds 18 bits.
    - 6 bits for each of the **red**, **green**, and **blue** colors.
- In analog VGA, analog colors of **RED**, **GREEN**, and **BLUE** replace digital red, green, and blue.
  - Allowing substantial increases of the number of colors supported.
  - VGA is downward compatible with CGA/EGA graphics.

16.3: GRAPHICS AND GRAPHICS PROGRAMMING Video memory size & color relation - VGA

- In VGA, 640 x 480 resolution with support for 256 colors displayed at one time will require a minimum of 640 x 480 x 8 = 2,457,600 bits of memory.

Due to architectural design there must be 256K bytes of memory available on the video board.

In ***planes*** of 64K bytes.

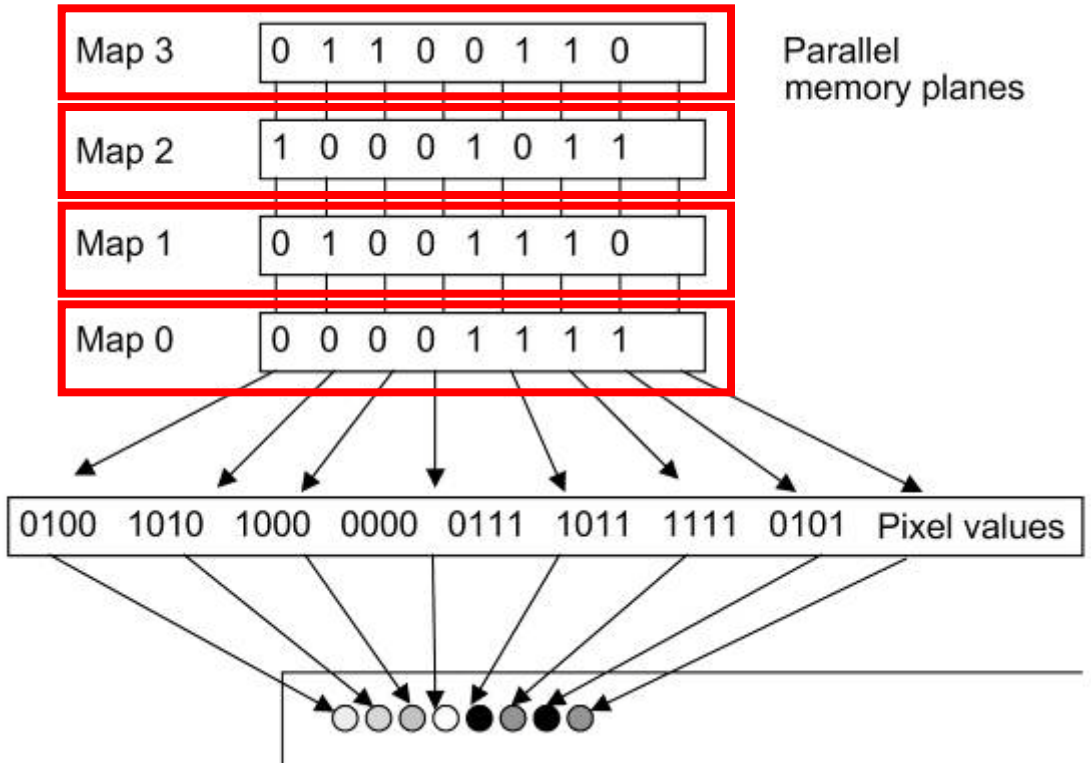


Fig. 16-9
16-Color EGA and VGA Mode Pixel Mapping

16.3: GRAPHICS AND GRAPHICS PROGRAMMING the case of SVGA

- In SVGA , all resolutions of 800 x 600, 1024 x 768, and 1024 x 1024 are supported.
  - Memory requirement for these boards can reach millions of bytes, depending on the number of colors supported.
    - 480,000 bytes is required for 800 x 600 pixels with 256 colors.

Table 16-4: Video Memory Requirements by Resolution

Resolution	16 Colors (4 bits)	256 Colors (8 bits)	65,536 Colors (16 bits)	16,777,216 Colors (24 bits)
640 x 480	256K	512K	1M	1M
800 x 600	256K	512K	1M	1.5M
1024 x 768	512K	1M	1.5M	2.5M
1280 x 1024	1M	1.5M	2.5M	4M
1600 x 1200	1M	2M	4M	6M

16.3: GRAPHICS AND GRAPHICS PROGRAMMING
INT 10H and pixel programming

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

16.3: GRAPHICS AND GRAPHICS PROGRAMMING drawing horizontal or vertical lines

- To draw a horizontal line, choose values for the row and column points at the beginning of the line.
  - Increment the column until it reaches the end of the line.
    - See Example 16-13 on page 443.

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