Chapter Two

Overview of Graphic I-O Devices

Computer Graphics is a study of generation of graphic images as diverse as line drawings and realistic rendering of natural objects. This requires both hardware and software that facilitate production of these images. There are many special purpose hardware which are basically used for generating and displaying graphic images. This chapter gives an overview of a graphic input and output devices and the logical functioning of these devices. Large majority of computer graphic systems utilize some type of CRT display and most of the fundamental display concepts are embodied in CRT display technology. The three most common types of CRT display technologies are direct view storage tube display, calligraphic refresh display and raster scan refresh display. The first two are line drawing displays while the third is a point-plotting device. An individual display may incorporate more than one technology. Cathode ray tube, which was discussed in the previous chapter, is the basis for all graphic devices. First we discuss about the types of displays that are used in computer graphics.

2.1 RANDOM SCAN DISPLAYS

The direct view storage tube display and calligraphic display are called random scan displays or line drawing displays. A line can be drawn directly from one addressable point to another.

Direct View Storage Tube Display

The direct view storage tube display is the simplest of all CRT display. It is a CRT with a long persistence phosphor. The line or character will remain visible nearly up to an hour unless it is erased. The intensity of the electron beam of the CRT is sufficiently increased to draw a line on the display. This effects the phosphor to get its bright state. It can be erased in half a second by flooding the entire tube with a specific voltage causing the phosphor to get in to dark state. The main difficulty is that all lines and characters are erased because the entire tube has to be flooded. This is the limitation for animation using this display. This is also why it is not useful for interactive drawings. However, it is flicker free. It is capable of displaying any number of lines and is easier to program.

Calligraphic Refresh Display

This is also a random scan display or a line drawing display. However it uses very short persistence phosphor. Because of the short persistence, the picture has to be redrawn on the CRT a number of times per second. This redrawing on the CRT is called refreshing the CRT. Generally the rate of refresh should be at least 30 times per second otherwise a flickering image will be seen which is quite irritating to the viewer.

In addition to the CRT this display requires two more elements called the display buffer and the display controller. The display buffer is contiguous memory containing all the information required to draw the picture on the CRT. The display controller takes this information and gives it to the CRT for display at the refresh rate. The number of lines that can be displayed depend on size of the display buffer and the speed of the display controller. Another limitation is the speed at which the information of the picture can be processed.

2.2 RASTER REFRESH GRAPHICS DISPLAYS

The raster graphics display is a point-plotting device based on the cathode ray tube. This may be viewed as matrix of discrete cells, called the raster, each of which can be made bright. Lines will be drawn as a series of dots called pixels along the path of the line specified by a line drawing algorithm. As lines are represented by a series of pixels they will appear as a staircase. This is called *aliasing effect* [see Fig. 2.1(a)].

Special cases like horizontal, vertical or diagonal lines with 45° angles will appear as straight lines. [see Fig. 2.1(b)].

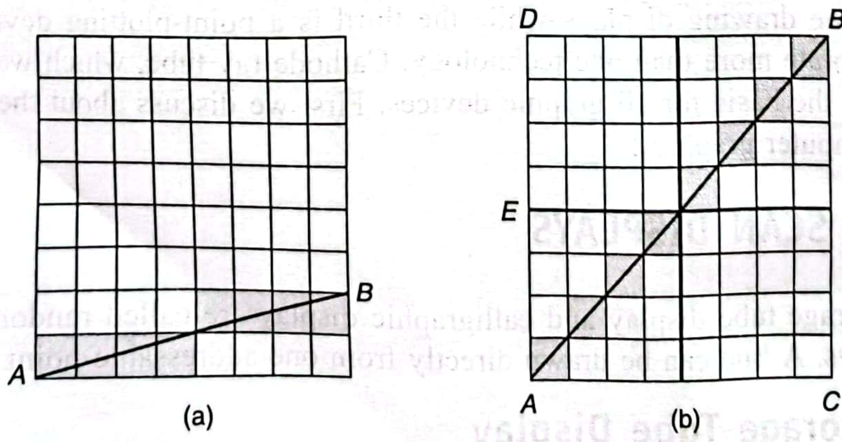

Fig. 2.1 *Rasterization (a) General Line (b) Special Cases*

Raster graphics display is implemented using a *frame buffer*. A frame buffer is a large, contiguous piece of computer memory. Each pixel is in the raster represented by at least one bit. This amount of memory of one bit per pixel is called a *bit plane*.

A 1024 × 1024 square raster requires 2^{20} bits in a single bit plane. The picture is built up in the frame buffer one bit at a time. A single bit plane yields a black-and-white or monochrome display, because a memory bit has only two states, namely, 0 or 1.

As the frame buffer is a digital device and the raster CRT is an analog device, we need a device to convert from a digital representation to an analog signal when information is read from the frame buffer and displayed on the raster graphics device. This is done by a *Digital-to-Analog Converter* (DAC). Figure 2.2 illustrates the raster graphics device with a single bit plane having a black and white frame buffer.

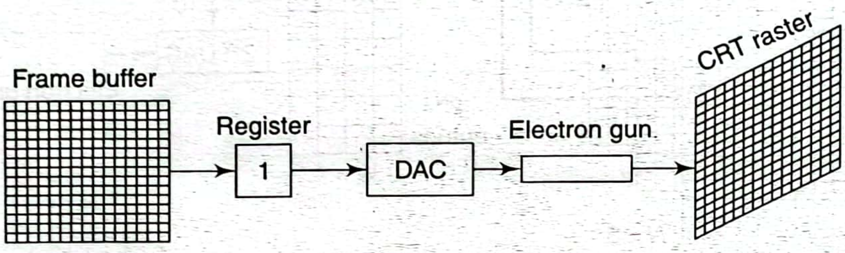

Fig. 2.2 *Raster Graphics Device with a Single Bit Plane having a Black and White Frame Buffer*

Using additional bit planes, color or gray levels can be incorporated into a frame buffer raster graphics device (see Fig. 2.3). In an N-bit plane frame buffer, the intensity of each pixel on the CRT is controlled by a corresponding pixel location in each of the N-bit planes. The bit from each of the N bit planes is loaded into corresponding positions in a register. The resulting binary number is interpreted as an intensity level between 0 and 2^N-1. The value 0 represents dark and

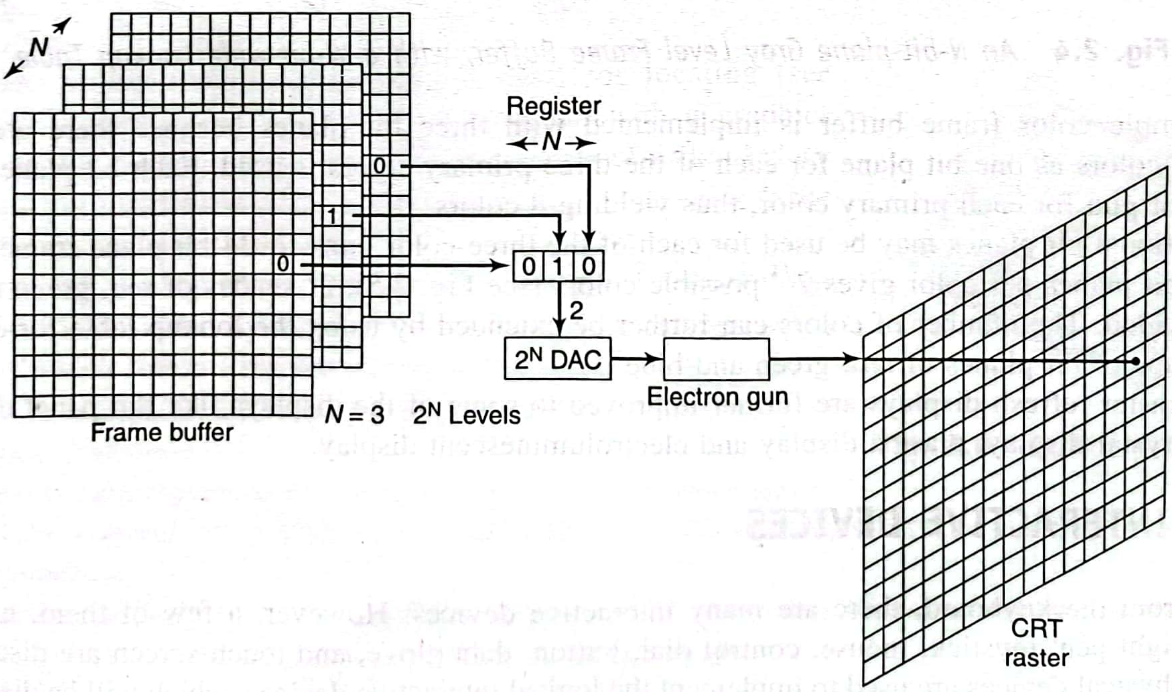

Fig. 2.3 *An N-bit Plane Gray Level Frame Buffer*

2^N-1 represents the full intensity level. This is converted into an analog voltage between 0 and the maximum voltage of the electron gun by the DAC, resulting in 2^N intensity levels or colors.

An increase in the number of intensity levels can be achieved by using a lookup table which is already discussed in chapter 1. After reading the bit planes in the frame buffer, the resulting number is used as an index into the lookup table. If there are N bit planes then the lookup table is a $2^N \times W$ sized table, where W is the number of columns. Thus 2^W colors are possible but only 2^N different intensities are available at one time (see Fig. 2.4).

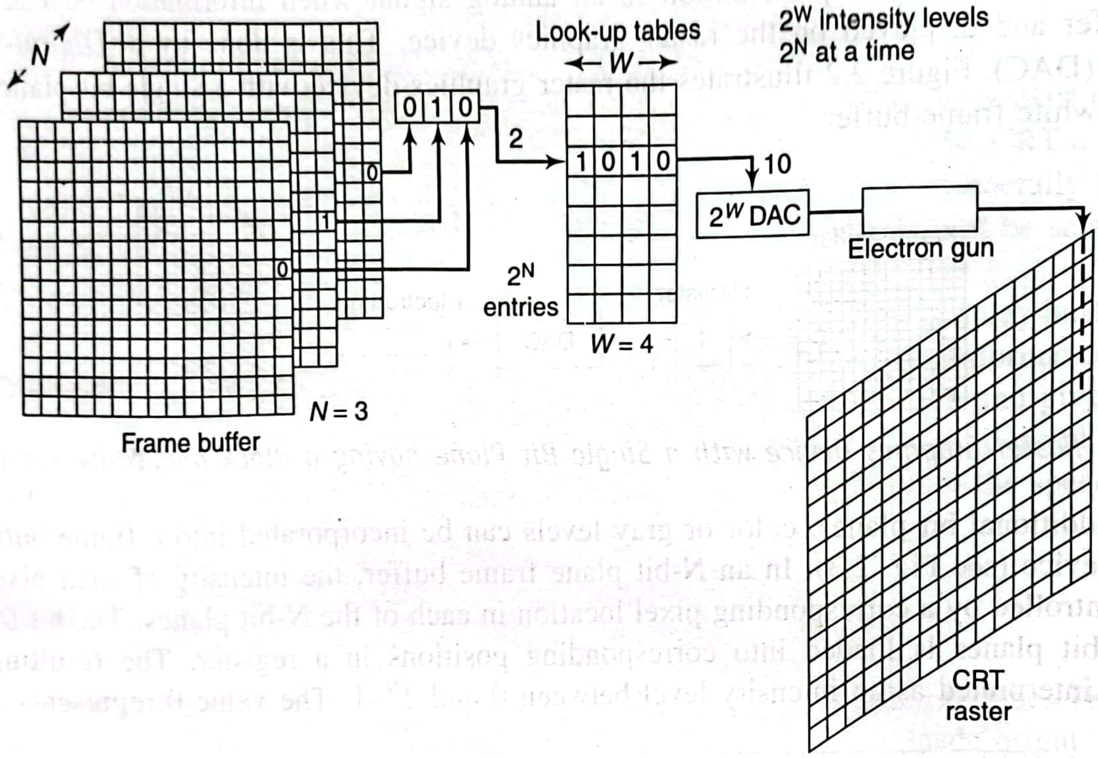

Fig. 2.4 *An N-bit-plane Gray Level Frame Buffer, with a W-bit-wide Lookup Table*

A simple color frame buffer is implemented with three bit planes because there are three primary colors as one bit plane for each of the three primary colors is used. Each bit plane drives one color gun for each primary color, thus yielding 8 colors.

Additional bit planes may be used for each of the three-color guns. A 24-bit plane frame buffer with 8 bit planes per color gives 2^{24} possible colors (see Fig. 2.5). 2^8 shades of red, green or blue are provided. The number of colors can further be extended by using the lookup table for each of the groups of bit planes of red, green and blue.

The raster refresh displays are further improved to some of the displays like flat panel display, liquid crystal display, plasma display and electroluminescent display.

2.3 INTERACTIVE DEVICES

Apart from the keyboard, there are many interactive devices. However, a few of them, namely, tablet, light pen, joystick, mouse, control dial, button, data glove, and touch screen are discussed. These physical devices are used to implement the logical interactive devices, which will be discussed in the next section.

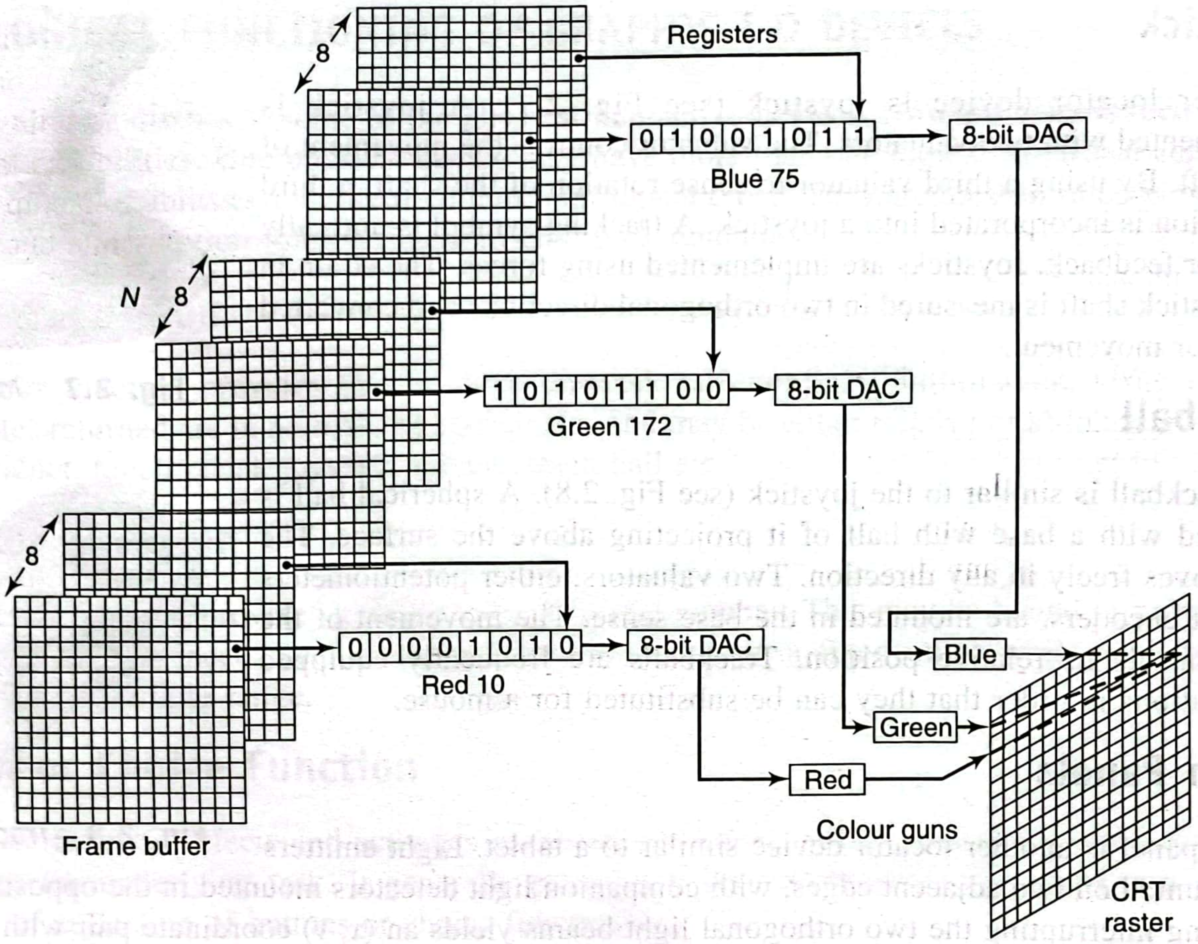

Fig. 2.5 *A 24-bit Plane Frame Buffer with 8 Bit Planes per Color gives 2^{24} Possible Colors*

Tablet

The tablet is the most common device used for locating (see Fig. 2.6). It may either be used in conjunction with a graphics display or standalone (called digitizer). It consists of a flat surface and a pen-like instrument called stylus. The stylus is used to indicate a location on the tablet surface.

When used in conjunction with graphics display, feedback from the display is provided by means of a small tracking symbol called a cursor, which follows the movement of the stylus on the tablet surface. Feedback is provided by digital readouts when used as standalone digitizer.

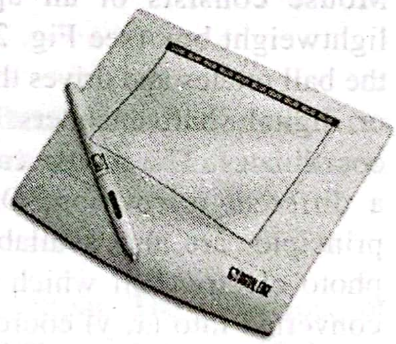

Fig. 2.6 *Tablet with Stylus*

Typically tablets provide two-dimensional coordinate information. The values returned are in tablet coordinates. Software is used to convert the tablet coordinates to world coordinates.

There are different principles used to implement tablets using wires, sound waves and using magnetic principles which are out of the scope of this book.

Joystick

Fig. 2.7 *Joystick*

Another locator device is joystick (see Fig. 2.7). A joystick is implemented with two valuators. The valuator controls the movement of the shaft. By using a third valuator to sense rotation of the shaft, a third dimension is incorporated into a joystick. A tracking symbol is normally used for feedback. Joysticks are implemented using forces. The strain in the joystick shaft is measured in two orthogonal directions and converted to cursor movement.

Trackball

Fig. 2.8 *Trackball*

The trackball is similar to the joystick (see Fig. 2.8). A spherical ball is mounted with a base with half of it projecting above the surface. The ball moves freely in any direction. Two valuators, either potentiometers or shaft encoders, are mounted in the base sense. The movement of the ball controls its relative position. Trackballs are frequently equipped with buttons in order that they can be substituted for a mouse.

Touch Panels

Touch panel is another locator device similar to a tablet. Light emitters are mounted on two adjacent edges, with companion light detectors mounted in the opposite edges. Anything interrupting the two orthogonal light beams yields an (x, y) coordinate pair with which a location is identified.

Mouse

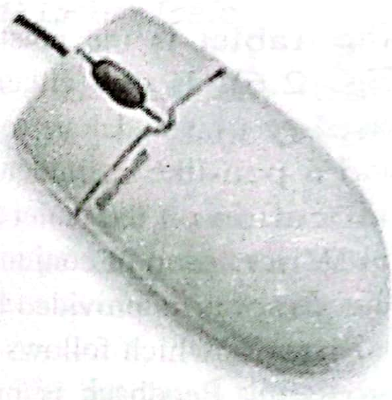

Fig. 2.9 *Mouse*

Mouse consists of an upside-down trackball mounted in a small, lightweight box (see Fig. 2.9). As the mouse is moved across a surface, the ball rotates and drives the shafts of two valuators, either potentiometers or digital shaft encoders. The movement of the shafts provides (x, y) coordinates. The mouse can be picked up, moved and set back down in a different orientation. Optical mouse and mouse based on magnetic principles are also available. These use small light source and a small photo electric cell which produce light pulses which are counted and converted into (x, y) coordinates.

Light Pen

Fig. 2.10 *Light Pen*

Light pen is a pick device. It contains a sensitive photoelectric cell. The basic information provided by the light pen is timing and hence it depends on the picture being repeatedly produced in a predictable manner.

There are many more devices that are useful for graphic applications which are not included in this book. Some of them are control dial, space ball, data glove, function switches, scanners and 3-D digitizers.

2.4 LOGICAL FUNCTIONING OF GRAPHIC I-O DEVICES

We have already discussed some of the physical interactive devices. Now we discuss their logical functional capabilities. One physical device may have more than one logical functional capability. The functional capabilities are classified into four logical types. They are locator function, valuator function, choice function (button function) and pick function.

Locator Function

The locator function provides two or three dimensional coordinate information. Generally, the coordinates returned are in normalized coordinates and may be either relative or absolute. Examples include tablet, touch panel, joystick, mouse, track ball etc.

Valuator Function

The valuator function provides a single value as a real number. This may be bound or unbound. A bound valuator has mechanical or programmed stops within a fixed range while an unbounded valuator has an infinite range.

Button or Choice Function

The choice function selects and activates events or procedures which control the interactive flow or change the underlying task. It generally provides binary information. Keyboard is a specific example of collection of buttons or choice functions.

Pick Function

The pick function selects objects within the displayed picture. It picks up the selected objects.

2.5 OUTPUT DEVICES

Apart from the display devices there are many output devices. Some of them are hard copy devices like inkjet printers, laser printers, plotters etc., the features of some of them are discussed below.

Inkjet Printers

These are raster scan devices and useful for generating low cost color output. The basic idea of these printers is to sprinkle very small drops of ink onto the medium (normally a paper). There are many types of inkjet printers depending on their flow. The resolution of inkjet printers is determined by the size of the drops, i.e. the size of the nozzle of the drops. As the nozzle size is very small, nozzle clogging, air bubbles and dry up of ink are some of the general problems of these printers. Color inkjet printers have four nozzles one for each color and one for black. Each of the three colors is blended together before drying to get the required color.

Laser Printers

A laser printer is also a raster scan device. The print engine contains a drum coated with some material which is photoconductive. The drum is scanned by a semiconductor diode laser. As the drum rotates, the coating is electrically charged and remains charged until it is struck by light from the laser. The light discharges selecting on the drum to form a negative image. A toner, which is a black powder, is attracted to the charged areas of the drum. The toner is fused to the paper using heat and pressure which forms a permanent image.

There are other devices like plotters etc. that are not discussed here as they are outside the scope of this book.

SOLVED PROBLEMS

2.1 What is a frame buffer?

A frame buffer is a large contiguous piece of computer memory.

2.2 What is a bit plane?

The amount of memory with one memory bit per pixel is called a bit plane.

2.3 How many colors are possible with three bit plane frame buffer raster graphics device?

$2^3 = 8$

2.4 In a 24-bit plane color frame buffer with a 10 bit wide lookup tables for each of the three colors, how many colors are possible at a given instant? How many total colors are possible?

There are 24 bit planes in which 8 each are assigned for each of the primary colors. Thus $2^{24} = 16{,}777{,}216$ colors are possible at any given instant. However the total colors are $2^{30} = 1{,}073{,}741{,}824$ because each of the 3 primary colors is assigned a 10 bit lookup table.

2.5 What is a locator?

Locator is a function of a physical interactive device that provides two or three dimensional coordinate information.

2.6 Give an example of a locator device.

Tablet

2.7 Give an example of a pick device.

Light pen

2.8 What is dpi?

Dots per inch

2.9 What is a Pixel?

The smallest addressable element of the screen is called a pixel (Picture element).

2.10 What is the minimum refresh rate of a raster scan display device?

30 frames/sec.

2.11 What is the job of a display controller?

The job of the display controller is to read the contents of the frame buffer and display it on the monitor at the required refresh rate (normally 30 times per second or more).

2.12 The frame buffer is a digital device and raster CRT is an analog device. How do we convert the digital information from the frame buffer on to the raster as a picture?

Using a Digital-to-Analog Converter (DAC)

2.13 In a 512 × 512 raster on a monochrome display with an average access rate of 200 nanoseconds per pixel, what is the refresh rate?

Access rate/pixel = 200 nanoseconds = 200×10^{-9} sec
Size of the raster = 512×512
No. of bit planes = 1 (monochrome display)
∴ Time required for accessing the raster = $200 \times 10^{-9} \times 512 \times 512 \times 1$ sec
$= 52428800 \times 10^{-9}$
∴ Refresh rate = No. of frames/sec $= 1/(52428800 \times 10^{-9})$
$= 19.07348633$
∴ Refresh rate = 19 frames/sec (approximately)

2.14 How many bits are required for a 512 × 512 raster with each pixel being represented by 3 bits?

$512 \times 512 \times 3 = 786342$ bits

2.15 What is the rate of a 1024 × 1024 frame buffer with an average access rate per pixel of 200 nanoseconds on a simple color display?

Access rate/pixel = 200 nanoseconds = 200×10^{-9} sec
Size of the raster = 1024×1024
No. of bit planes = 3 (simple color display)
∴ Time required for accessing the raster = $200 \times 10^{-9} \times 1024 \times 1024 \times 3$ sec
$= 629145600 \times 10^{-9}$

$\therefore$ Refresh rate = no. of frames/sec $= 1/(629145600 \times 10^{-9})$
$= 1.58945$

$\therefore$ Refresh rate = 1.6 frames/sec (approximately)

2.16 How many pixels are there in a 1024 × 1024 frame buffer?

$1024 \times 1024 = 2^{20}$ pixels

SUPPLEMENTARY PROBLEMS

2.1 How many memory bits are required for a 24-bit plane 1024 × 1024 element raster?

2.2 What are the bit representations of the RGB color combinations of a simple 3-bit plane frame buffer?

2.3 What is the access rate/pixel of a 4096 4096 raster having a refresh rate of frames/sec?

ANSWERS TO SUPPLEMENTARY PROBLEMS

2.1 24 × 1024 × 1024 memory bits

2.2

	Red	Green	Blue
Black	0	0	0
Red	1	0	0
Green	0	1	0
Blue	0	0	0
Yellow	1	1	0
Cyan	0	1	1
Magenta	1	0	1
White	1	1	1

2.3 $1/(30 \times 4096 \times 4096)$ seconds = nanoseconds approximately