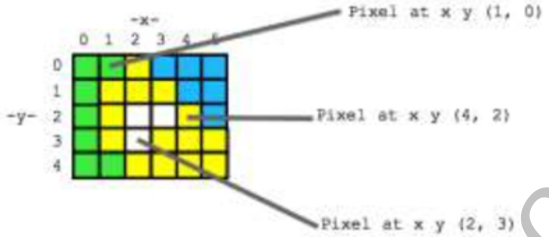
Chapter 1
Graphics Hardware

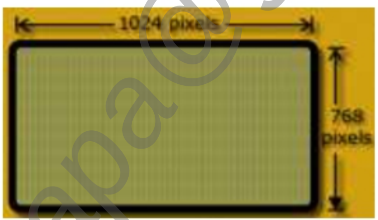
Basic Terminologies Related to Computer Graphics

- Image
  - An image is a 2 dimensional light intensity function f(x,y) where (x,y) are the spatial co-ordinate and f(x, y) is proportional to brightness or intensity or gray value of the image at that point.



- Pixel (or Pel)
  - Computer graphics consists pictures or images which are collection of discrete addressable picture elements called pixels.
  - Each pixel has its own gray level or intensity, name or address by which we can control.

- Resolution
  - The number of pixels in horizontal direction and vertical direction on the screen is called resolution.
  - Example: For a resolution of 1024 * 768, 1024 pixels are going horizontally and 768 pixels are going vertically.



- Aspect Ratio
  - It is defined as the ration of horizontal points to the vertical points required to produce equal length lines in both the direction of the screen.
  - It is given by the following formula.

    Aspect Ratio = No of horizontal points / No of vertical points
  - For example: (800 * 600) pixels in the display has the aspect ratio 800/600 = 4/3 i.e. 4:3
  - An aspect ratio of 4:3 means that a vertical line is plotted with 3 points has the same length as horizontal line plotted with 4 points. Generally, the aspect ratio is not one.
  - The main difference between resolution and aspect ratio is that aspect ratio is the shape that the picture takes while the resolution is the number of pixels in that shape.

- Bit Plane
  - There is one memory bit for each pixel in raster display system.
  - This amount of memory is called bit plane.
  - The picture is built up in the frame buffer, one bit at a time.
  - A memory bit has only two states, 0 or 1, so a single bit plane yields a black and white display.
  - However, we can increase the levels of intensity level by increasing the number of bit planes.

- Bit Depth (Or Color Depth)
  - It is defined as number of bits assigned to each pixel in the image.
  - It specifies the number of color that a monitor can display.
  - For example: 1 bit per pixel represent, $2^1 = 2$ colors for each pixel, similarly 1 byte i.e. 8 bits represents $2^8 = 256$ colors for each pixel.

- Refresh Rate

- It is defined as the number of times per second the pixels are recharged so that the image doesn't flicker. It is measured in hertz(hz).
- It is also called as frame rate, horizontal scan rate, vertical frequency or vertical scan rate.
- Normally the refresh rate varies from **60 to 80hz**.
- A refresh rate of 75 hz means that the image is redrawn 75 times a second.
- Higher the refresh rate, the lesser is the flickering.

- Bit Map and Pixel Map
  - If a pixel has only two color values (i.e. black and white), it can be encoded by a 1 bit of information. On a black and white system with one bit per pixel, the frame buffer is called bitmap.
  - An image of more than two colors is called pix map.

- Aliasing
  - Aliasing is distortion that appear in any display system when the sampling the continuous object to discrete integer pixel position.

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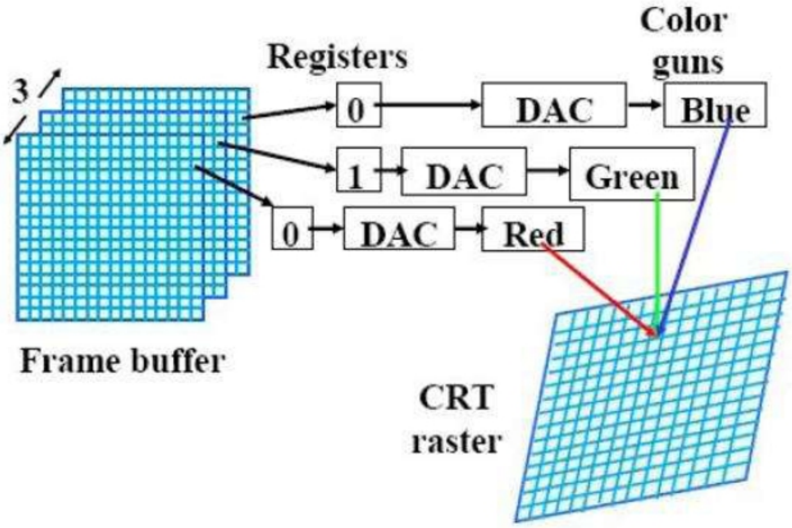
  - This is because, lines, polygon, circle etc. are continuous but a raster device is discrete.
  - The process of reducing the effect of aliasing is called anti-aliasing. An aliasing problem may be due to the low resolution, so one of the easiest solution is to increase the resolution.

- Frame (or Refresh) Buffer
  - It is a large, contiguous piece of memory into which the intensity values for all pixels are placed.
  - At a minimum there is one memory bit for each pixel in the raster; this amount of memory is called a bit plane.
  - It stores the internal representation of image.
  - Graphics processor passes the content of framebuffer to the display system.
  - *Figure given below illustrates a system with N=3 bit planes for a total of 8 (2^3) intensity levels.*
  - *The frame buffer is a digital device and the CRT is an analog device. Therefore, a conversion from a digital representation to an analog signal must take place when information is read from the frame buffer and displayed on the raster CRT graphics device. For this you can use a digital to analog converter (DAC). This is converted into an analog voltage between 0 and the maximum voltage of the electron gun by the DAC. Each pixel in the frame buffer must be accessed and converted before it is visible on the raster CRT.*
  - *Because there are three primary colors, a* ***simple color*** *frame buffer is implemented with three bit planes, one for each primary color. Each bit plane drives an individual color gun for each of the three primary colors used in color video. These three primaries (red, green, and blue) are combined at the CRT to yield* ***eight*** *colors.*



Simple Color buffer

Input Devices

i. **Keyboard**
ii. **Mouse**
iii. **Trackball**
iv. Joystick
v. Data Gloves
vi. Digitizers and Graphics tablet
vii. Image Scanners
viii. **Touch Panels**
ix. **Light Pens**
x. Voice System

Output Devices

i. Hardcopy Output Device
  1. Printers
    i. Impact vs non-impact printer
    ii. Dot matrix printer
    iii. Ink jet printer
    iv. Laser Printer
    v. Line Printer
    vi. Electrostatic Printer
  2. Plotter
ii. Display Devices
  a. CRT

Cathode Ray Tube

- A CRT monitor displays color pictures by using a combination of phosphors (phosphorescent substance) that emit different colored light.

Working Principle

- A beam of electron (cathode rays), emitted by an electron gun, passes through focusing and deflection system that directs the beam toward specified positions on the phosphor coated screen.
- The phosphor then emits a small spot of light at each position contacted by the electron beam.
- Since the light emitted by the phosphor fades very rapidly, so to keep the phosphor glowing it is necessary to redraw the picture repeatedly by directing the electron beam back over the same points. This technique is called as refreshing CRT.

- Persistence is the property which tells how long the phosphor continues to emit light after the electron beam is removed.
- *Persistence of phosphor is defined as the time it takes for emitted light to decay to 1/10 (10%) of its original intensity.*
- *Lower persistence phosphor requires high refresh rate to maintain picture in the screen without flickering.*

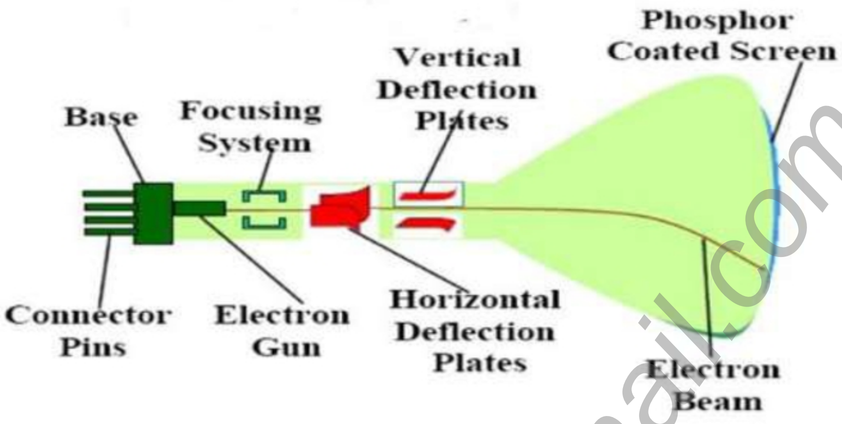


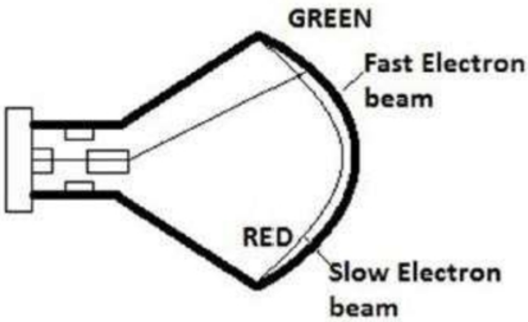
Fig: Architecture of CRT

- The above figure shows the basic architecture of CRT.
- The primary components of CRT are heated cathode metal (electron gun), focusing system, and deflection plates.
- Heat is supplied to the cathode by directing a current through a coil of wire. This causes negatively charged electrons to be emitted.
- This negatively charged electrons are directed toward phosphor coating via focusing anode.
- Two pair of deflection plates are used to direct the beam to required position in phosphor coated screen: vertical deflection plate and horizontal deflection plate.
- The vertical deflection plate is used to move the beam up and down.
- The horizontal deflection plate is used to move the beam left and right.

Color CRT

- In color CRT, the phosphors on the face of CRT screen are laid in two different fashion.
- Depending on the technology of CRT there are two methods for displaying the color pictures into the screen.
  i. Beam Penetration Method
  ii. Shadow Mask Method

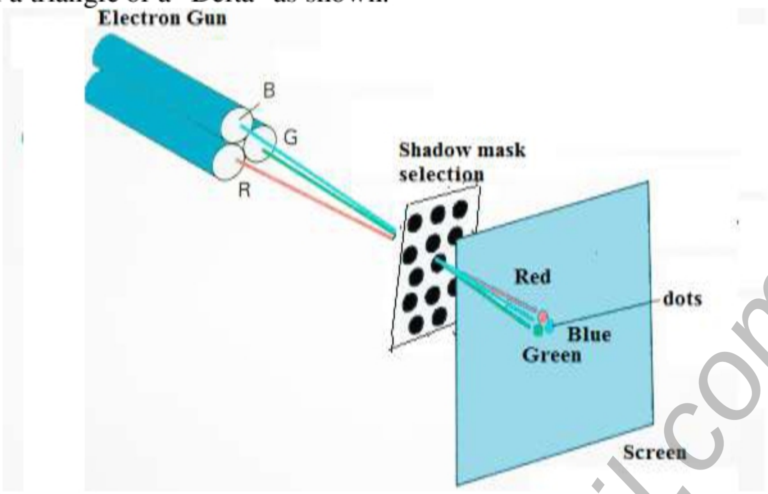
Beam Penetration Method



- The beam penetration method is for the random scan monitor display where two different layers of phosphor coating are used, Red (outer) and Green (inner) coated on the CRT screen.
- In this method, only four colors possible and hence the poor picture quality
- A beam of slow electrons excites only the outer red layer
- A beam of very fast electrons penetrates through the red phosphor and excites the inner green layer.
- Intermediate speed of electron provides two additional colors: orange and yellow
- When quantity of red is more than green then orange color appears.
- When quantity of green is more than red then yellow color appears.

Shadow Mask Method

- Shadow mask method is used for raster scan system so they can produce wide range of colors
- The shadow mask CRT, instead of using one electron gun, uses 3 different guns placed one by the side of the other to form a triangle or a "Delta" as shown.



- Each pixel point on the screen is also made up of 3 types of phosphors to produce red, blue and green colors.
- Just before the phosphor screen is a metal screen, called a "shadow mask".
- This metal plate has holes placed strategically, so that when the beams from the three electron guns are focused on a particular pixel, they get focused on particular color producing pixel only

Display System

i. **Raster Scan Display System**
ii. **Random Scan Display System**

Refresh or Raster Scan Display System

- In its simplest form, a raster consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information, such as intensity level.
- In this display system, raster points are used as basic drawing primitives.

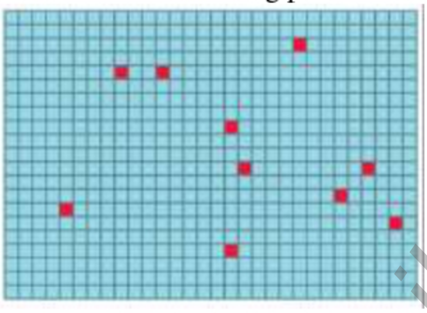
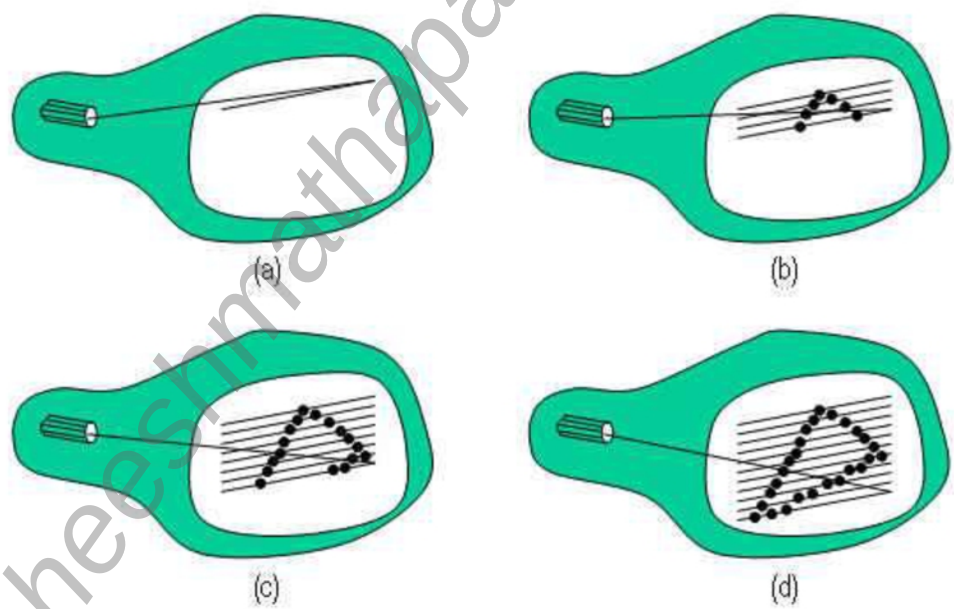


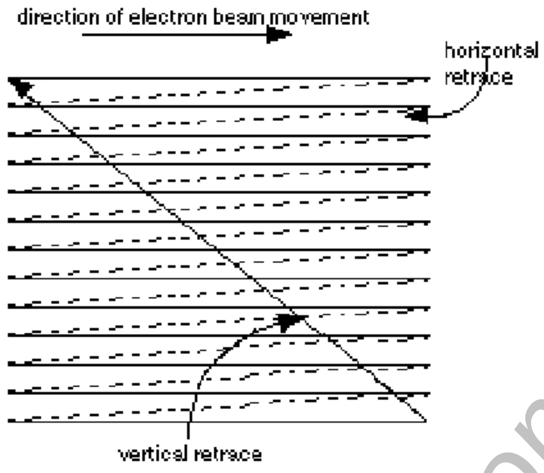
Fig: Raster Points

- Make use of scan line to draw pictures.
- In raster-scan the electron beam is swept across the screen, one row at a time from top to bottom.
- Picture definition is stored in a memory called frame buffer or refresh buffer.
- Frame buffer holds all the intensity value for screen points.
- As electron beam moves across each row, the beam intensity is turned on and off to create a pattern of illuminated spots.
- Refreshing on raster-scan displays is carried out at the rate of 60 to 80 frames per second.

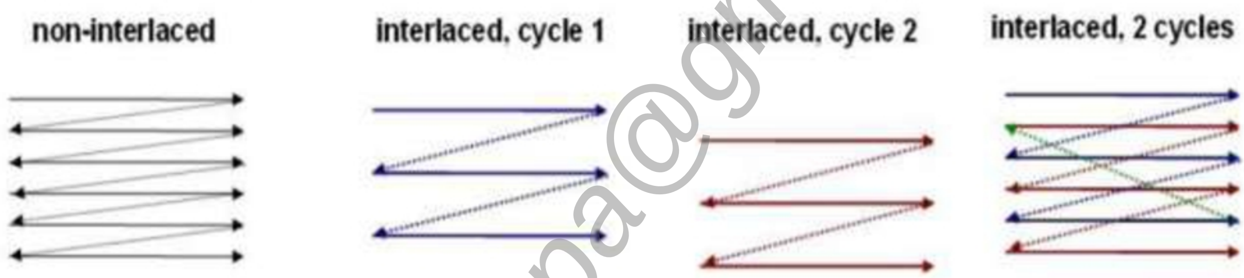


- Each scan line in display device consists of two retrace
  i. Horizontal retrace
     - At the end of each scan line, the electron beam returns to the left side of the screen to begin displaying the next scan line. This is called horizontal retrace.

  ii. Vertical retrace
     - At the end of each frame, the electron beam returns to the top left corner to begin the next frame. This is called vertical retrace.



- On some raster-scan system each frame is displayed in two passes using and interlaced refresh procedure. In the first cycle the beam sweeps across odd scan line from top to bottom (1, 3, 5 and so on). Then after vertical retrace, the beam sweeps out the remaining even scan lines (2, 4, 6 and so on). *This technique allows us to see the entire screen displayed in one-half the time it would have taken to sweep across all the lines at once from top to bottom.* Interlacing is primarily used with lower refreshing rate. This is a very good technique for avoiding screen flickering, this is because adjacent scan lines contain similar display information.



- **Home television (CRT) and printers** are example of systems using raster scan method.

Architecture of Raster Scan Display System

- A special purpose processor, called video controller or display controller is used to control the operation of the display device.
- The below figure shows the commonly used raster system organization.

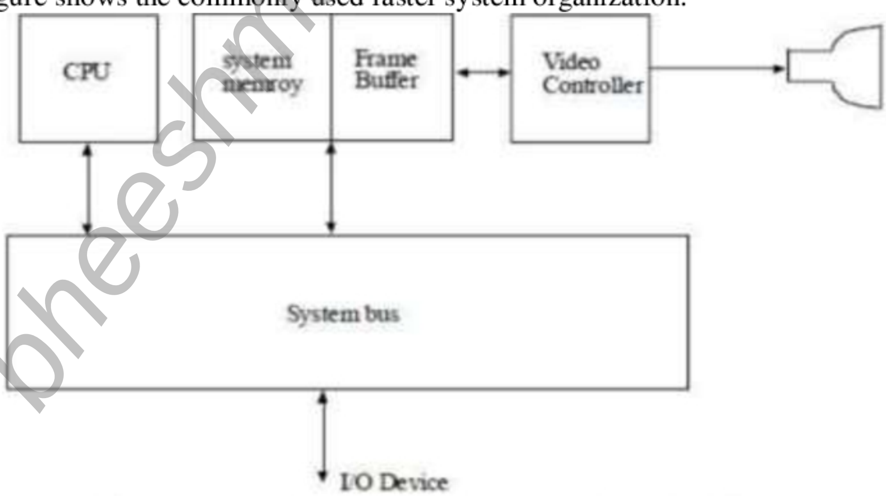


Fig. Architecture of a raster system with a fixed positon of the system memory requred for the frame buffer

- A fixed area of memory is reserved for frame buffer, and the video controller is given direct access to the frame buffer
- When a particular command is called by the application program, the graphics subroutine package sets the appropriate pixels in the frame buffer.

- The video controller then cycles through the frame buffer, one scan line at a time, typically 50 times per second.
- It will bring a value of each pixel contained in the frame buffer and uses it to control the intensity of the CRT electron beam.
- So there exists a one to one relationship between the pixel in frame buffer and that on the CRT screen.

Refresh Operation of Video Controller

- Frame buffer locations, and the corresponding screen position are referenced in Cartesian co-ordinates.
- For most of the system, the coordinate origin is referenced at the lower left corner of the screen, with positive X value increasing to the right and positive y value increasing from bottom to top. However, in some PC, the coordinate origin is referenced at the upper left corner of the screen, so the y values are inverted.
- The below figure shows the basic refresh operation of video controller.

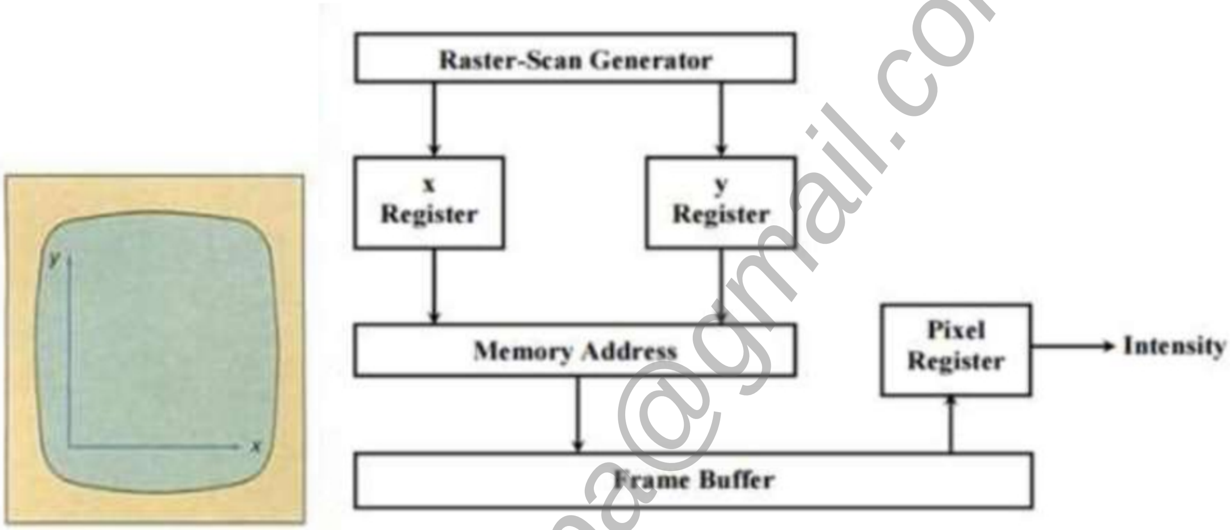
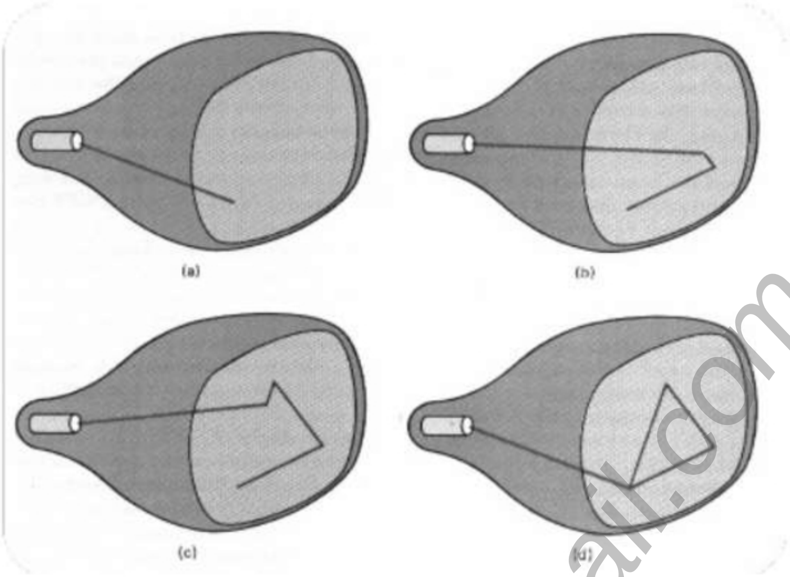


Fig: Basic Video Controller Refresh Operation

- Two registers are used to store the coordinates of the screen pixels; x register is used to store x coordinate
- and y register is used to store y-coordinate.
- The intensity value is stored in the frame buffer for this pixel position is then retrieved and used to set
- the intensity of the CRT beam.
- Initially the x-register is set to 0 and the y register is set to ymax. Then the x-register is incremented by 1,and the process repeated for the next pixel on the top scan line until x = xmax.
- This process is repeated for each pixel along the scan line.
- After the last pixel on the top scan line has been processed, the x-register is reset to 0, and the y-register is decremented by 1.
- This process is repeated for each successive scan line until the bottom scan line where y=0.

Random or Vector Display System

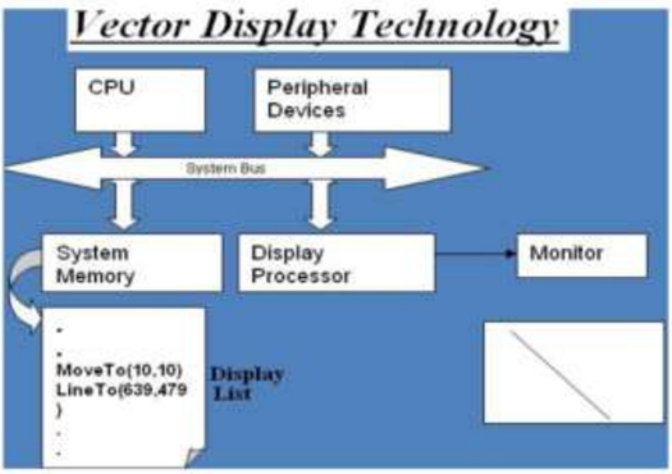
- In random scan system, the display monitor (CRT) has the electron beam that is directed only to the parts of the screens where the picture is to be drawn.



- It draws a picture with one line at a time, so it is also called vector display (or stroke writing or calligraphic display).
- The component lines of a picture are drawn and refreshed by random scan system in any specified order.
- Picture definition is now stored as a set of line- drawing command in an area of memory called refresh display file or simply refresh buffer.
- To display a specified picture, the system cycles through the set of commands in display file, drawing each component in turn.
- After all line drawing commands have been processed, the system cycles back to the first line drawing command in the list.
- Random scan system is designed for line drawing application so they can't draw realistic shaded scene because picture definition is stored as a set of line drawing commands no as a set of intensity values.
- Vector display system produce smooth line drawing because electron beam directly follow the line path but in case of raster system, it produces jagged lines.
- Vector display system only works with high end processor.
- For vector system, refreshing a complex image with many line may cause flickering effect but this is not the case in raster system.
- Example: Plotter

Architecture for Random Scan System

- The organization of simple Random scan system is shown in the figure below.



- An application program is input and stored in the system memory along with the graphics package.
- The graphics command in the application program are translated by the graphics package into a display list stored in system memory.
- The display list is accessed by the display processor to refresh the screen.
- The display processor cycles through each command in the display list once during each refresh cycle.
- Graphics pattern are drawn by directing the electron beam along the component lines of the picture.
- Lines are defined by the values for their co-ordinate endpoints.
- A scene is then drawn one line at a time by positioning beam to fill in the line between specified endpoints.

Note

8bit= 1 byte
1024byte = 1 kilobyte
1024kilobyte= 1Megabyte
1024Megabyte= 1 Gigabyte

Solved Numerical Problems

1. **A system with 24 bits per pixel and resolution of 1024 by 1024. Calculate the size of frame buffer (in Megabytes)**
   Solution:
   Resolution = 1024 * 1024
   Total number of pixel = 1024 * 1024 = 1048576pixels
   Bits per pixels' storage = 24 bits
   Therefore, total storage required in frame buffer = 1048576 * 24
   = 25165824bits
   =25165824/8 Byte
   = 25165824/(8 * 1024) Kb
   = 25165824/(8 * 1024 * 1024) Mb
   = 3 Mb

2. How Many k bytes does a frame buffer needs in a 600 x 400 pixel?

   Suppose, n bits are required to store 1 pixel.
   Then, the size of frame buffer = Resolution * bits per pixel
   = (600 * 400) * n bits
   = 240000 n bits
   = 240000 n kb / (8 * 1024)
   = 29.30 n k bytes.

3. **Consider a RGB raster system is to be designed using 8 inch by 10-inch screen with a resolution of 100 pixels per inch in each direction. If we want to store 8 bits per pixel in the frame buffer., how much storage in bytes do we need for the frame buffer?**
   Solution:
   Size of screen = 8inch * 10inch
   Pixels Per inch (Resolution) = 100
   Then total number of pixels = 8 * 100 * 10 * 100 = 800000 pixels
   Bits per pixels' storage =8
   Therefore, total storage required in frame buffer = 800000 * 8 bits
   = 6400000bits
   I = 6400000/8 bytes
   = 800000Bytes

4. **Find out the aspect ratio of the raster system using 8 x 10 inches' screen and 100 pixels/inch.**
   Solution:
   We know that, Aspect ratio = No. of horizontal pixels / No. of vertical pixels
   = (8 x 100) / (10 * 100)

= 4 / 5
So, aspect ratio = 4: 5

5. What is the time required to display a pixel on the monitor of size 1024 * 768 with refresh rate of 60 Hz?

Solution:

Refresh Rate = 60Hz i.e. 60 frames per second
Total number of pixel in one frame = 1024 * 768 = 786432 pixels.
60 frames need 1 second
1 frame need 1 / 60 second
i.e. 786432 pixels need 1/ 60 second
hence, 1 pixels need 1 / (60 * 786432) second
= 10^9 / (60 * 786432) ns
= 21.19 ns

6. If the total intensity achievable for a pixel is 256 and the screen resolution is 640 * 480. What will be the size of frame buffer?

Solution:

1 pixel =256 different intensity level
Resolution = 640 * 480
Let X be the number of bits required to represent 256 different intensity level
Then, $2^X = 256$
Therefore, X= 8 bits
Hence, number of bits required for the screen = 640 * 480 * 8 = 2457600 bits.

7. If a pixel is accessed from the frame buffer with an average access time of 300ns then will this rate produce an un-flickering effect for the screen size of 640 * 480.

Solution:

Size of screen = 640 * 480
Total Number of pixels = 640 * 480 = 307200
Average access time of one pixel = 300ns
Therefore, total time required to access entire pixels of image in the screen = 307200 * 300
= 92160000 ns
= 92160000/10^9
= 0.09216 seconds

i.e. 1 cycle take 0.09216 second
now, Number of cycles per second i.e. Refresh Rate =?
0.09216 seconds = 1 cycle
1 second = 1/ 0.09216
= 10.86

Or simply, Refresh Rate=Frequency = 1/time = 1/0.09216 = 10.86

Therefore, Refresh Rate= 10.86 cycles per second
Since the minimum refresh rate for unflicker image is 60 frames per second, hence we can say the monitor produces flickering effect.

8. Consider a raster scan system having 12-inch by 12-inch screen with a resolution of 100 pixels per inch in each direction. If display controller of this system refresh the screen at the rate of 50 frames per second, how many pixels could be accessed per second and what is the access time per pixel of the system.

Solution:

Size of Screen = 12inch * 12inch
Resolution: = 100pixels per inch
Therefore, total number of pixels in one frame = 12 * 100 * 12 * 100
Refresh Rate = 50 frames per second i.e. 50 frames can be accessed in 1 second

Therefore, total number of pixel accessed in 1 second = 50 * 12 * 100 * 12 * 100
= 72000000 pixels.

Again,
Since, 50 frames can be accessed in 1 second
1 frame can be accessed in 1/50 second
i.e. (12 * 100 * 12 * 100) pixels can be accessed in 1/50 second
then 1 pixel can be accessed in 1 / (50 * 12 * 100 * 12 * 100) second
= 10^9 / (50 * 12 * 100 * 12 * 100) ns
=13.88 ns
Hence, Access time per pixel = 13.88ns/pixel.

9. How much time is spent scanning across each row of pixels during screen refresh on a raster system with resolution 1280 * 1024 and refresh rate of 60 frames per second? (TU Exam)

Solution:

Resolution = 1280 * 1024 i.e. One frame contains 1024 scan line and each scan line consists of 1280 pixels.

Refresh Rate = 60 frames per second
i.e. 60 frame take 1 second
1 frame take 1/60 second
i.e. 1024 scan line take 1/60 second i.e. 0.0166 second
1 scan line take 0.0166/1024 = 0.016 Ms.

10. What is the size of frame buffer required to store a SVGA with 24-bit true color video of 10 minute without compression?

Note: A digital movie is a sequence of video frames in which each frame is a full color still image.

Resolution Info of different Display Hardware
SVGA: 800 * 600 (Super Video Graphics Array)
VGA: 640 * 480 (Video Graphics Array)
XGA: 1024 * 768 (Extended Graphics Array)
HD720: 1280 * 720 (High Definition)
FHD1080: 1920 * 1080

Solution:
For SVGA, Resolution = 800 * 600
Refresh Rate = 60Hz i.e. 60 frames per second
So each second can play 60 frames

Total number of pixel in one frame= 800 * 600
Bits per pixel = 24 bit
Therefore, total storage required for one frame buffer = 800 * 600 * 24 bits

Now how many frame buffer required for 10 minutes' videos?
We know, 10 minutes = 10 * 60 seconds = 600 seconds

Since, size of frame buffer for 1 second = 60 * 800 * 600 * 24 bits
Hence, size of frame buffer for 600 seconds i.e. 10 min video = 600 * 60 * 800 * 600 * 24 bit
= 48.27 GB

11. Differentiate between raster and random display system.

Vector Scan Display	Raster Scan Display
1. In vector scan display the beam is moved between the end points of the graphics primitives.	1. In raster scan display the beam is moved all over the screen one scan line at a time, from top bottom and then back to top,
2. Vector display flickers when the number of primitives in the buffer becomes too large.	2. In raster display, the refresh process is independent of the complexity of the image.
3. Scan conversion is not required.	3. Graphics primitives are specified in terms of their endpoints and must be scan converted into their corresponding pixels in the frame buffer.
4. Scan conversion hardware is not required.	4. Because each primitive must be scan-converted,real time dynamics is for more computational and requires separate scan conversion hardware.
5. Vector display draws a continuous and smooth lines.	5. Raster display can display mathematically smooth lines, polygons, and boundaries of curved primitives only by approximating them with pixels on the raster grid.
6. Cost is more.	6. Cost is low.
7. Vector display only draws lines and characters.	7. Raster display has ability to display areas filled with solid colours or patterns.

Presentation Topic / Assignment-1

1. Briefly explain different input devices (Keyboard, Mouse, Trackball and Space ball, Joystick, Data Gloves, Digitizers, Image Scanners, Touch Panels, Light Pens, Voice System).
2. Briefly explain hardcopy device (Types of Printer).
3. Write short notes on following display device
   i. CRT
   ii. Flat panel display
   iii. Plasma panel display
   iv. LCD display

Reference Book:
Computer Graphics, Donald D. Hearn

Note

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