Computer Graphics

Introduction to Computer Graphics and Graphics Systems

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Introduction

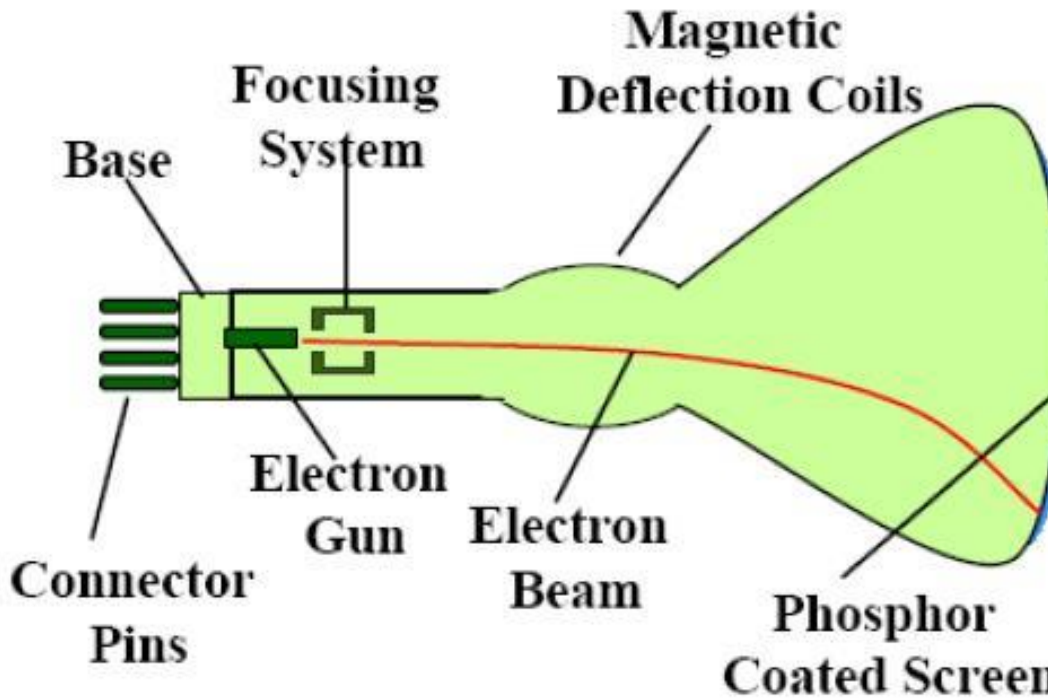
- Computer Graphics is the illustration field of Computer Science. Its use today spans virtually all scientific fields and is utilized for design, presentation, education and training. Computer Graphics and its derivative, *visualization*, have become the primary tools by which the flood of information from Computational Science is analyzed.
- The effective construction of three-dimensional computer-generated illustrations is not only a computer science problem, it is a problem that involves other fields as well.
- For example, It depends heavily on mathematics for its geometric basis and computational algorithms, and it depends on Physics for its principles of geometric optics (the reflection of light from surfaces determines the displayed color of the surface).
- It is also the study of a field that provides methods by which illustrations can be generated by others.

Uses of Computer Graphics

- User Interfaces
- (Interactive) plotting in business, science, and technology
- Office automation and electronic publishing
- Computer-aided drafting and design
- Simulation and animation for scientific visualization and entertainment
- Art and commerce, Education and Training
- Computer Art
- Entertainment
- Visualization
- Image Processing
- Process control
- Cartography

Graphics Hardware

- Video Display Devices --- cathode-ray tube (CRT)
- Basic design of magnetic – deflection CRT



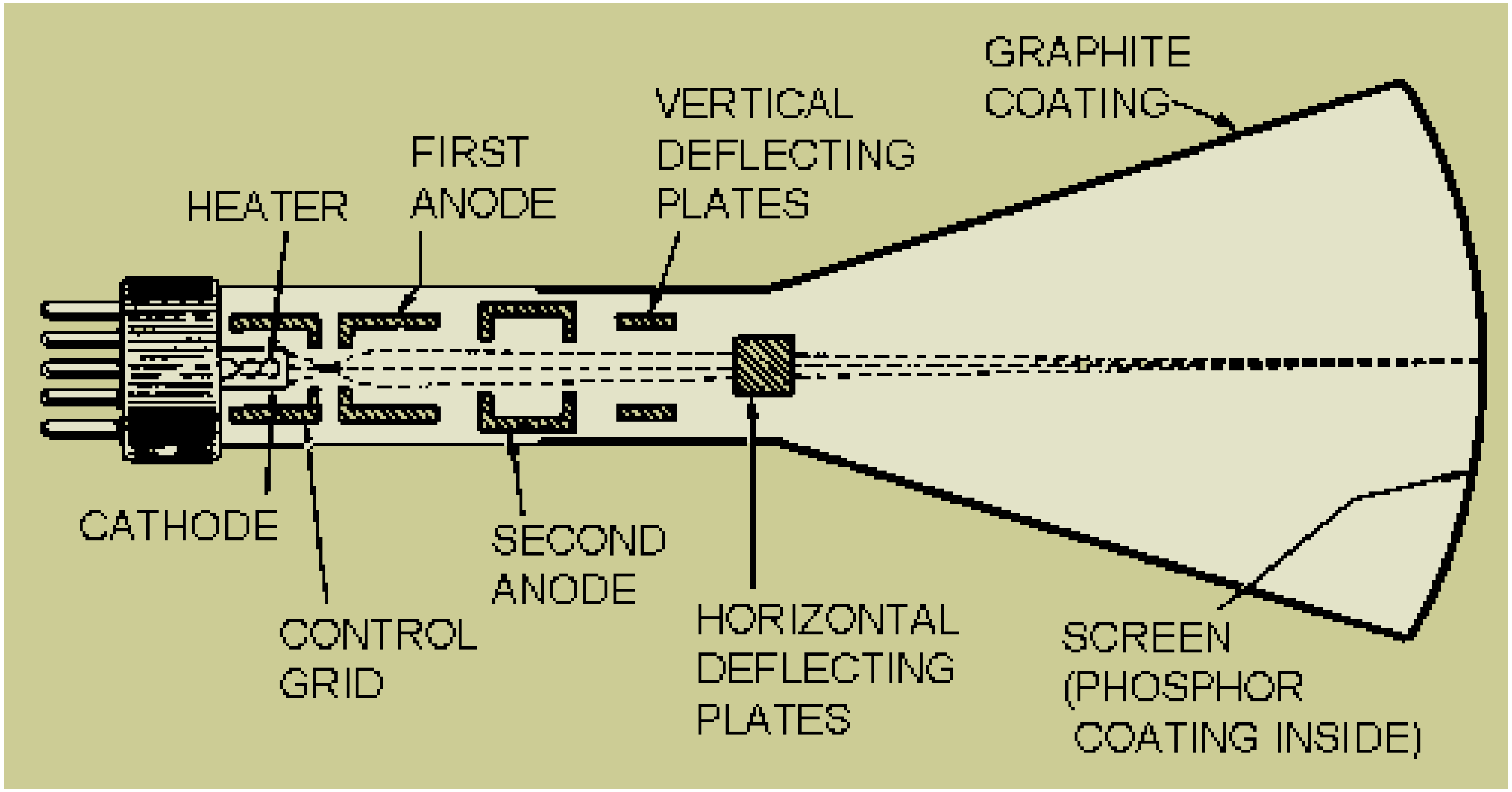
Basic design of a magnetic deflection CRT

Refresh Cathode-Ray Tubes

- A beam of electrons (cathode rays)
  - emitted by an electron gun
  - passes through focusing and deflection systems
  - that direct 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.
  - The light emitted by the phosphor fades very rapidly
  - phosphor glowing -> redraw the picture repeatedly by quickly directing the electron beam back over the same points
  - This type of display is called a ***refresh CRT***

Component of Electron Gun

- Heated Metal Cathode
- A Control Grid



Working Principle of Electron Gun

- Heat is supplied to the cathode by directing a current through a coil of wire, called the filament, inside the cylindrical cathode structure
- This causes electrons to be “boiled off" the hot cathode surface
- In the vacuum inside the CRT envelope, the free, negatively charged electrons are then accelerated toward the phosphor coating by a high positive voltage
- The accelerating voltage can be generated with a positively charged metal coating on the inside of the CRT envelope near the phosphor screen
- *Sometimes the electron gun is built to contain the accelerating anode and focusing system within the same unit*

Working Principle of Electron Gun

Control Grid: metal cylinder that fits over the cathode

- Intensity of the electron beam is controlled by setting voltage levels on the control grid
- A high negative voltage applied to the control grid will shut off the beam by repelling electrons and stopping them from passing through the small hole at the end of the control grid structure.
- A smaller negative voltage on the control grid simply decreases the number of electrons passing through.
- Since the amount of light emitted by the phosphor coating depends on the number of electrons striking the screen, we control the brightness of a display by varying the voltage on the control grid

Working Principle of Electron Gun

Focusing:

- to force the electron beam to converge into a small spot as it strikes the phosphor
  - Otherwise, the electrons would repel each other, and the beam would spread out as it approaches the screen
- Focusing is accomplished with either electric or magnetic fields
- Electrostatic focusing is commonly used in television and computer graphics monitors
  - electron beam passes through a positively charged metal cylinder that forms an electrostatic lens

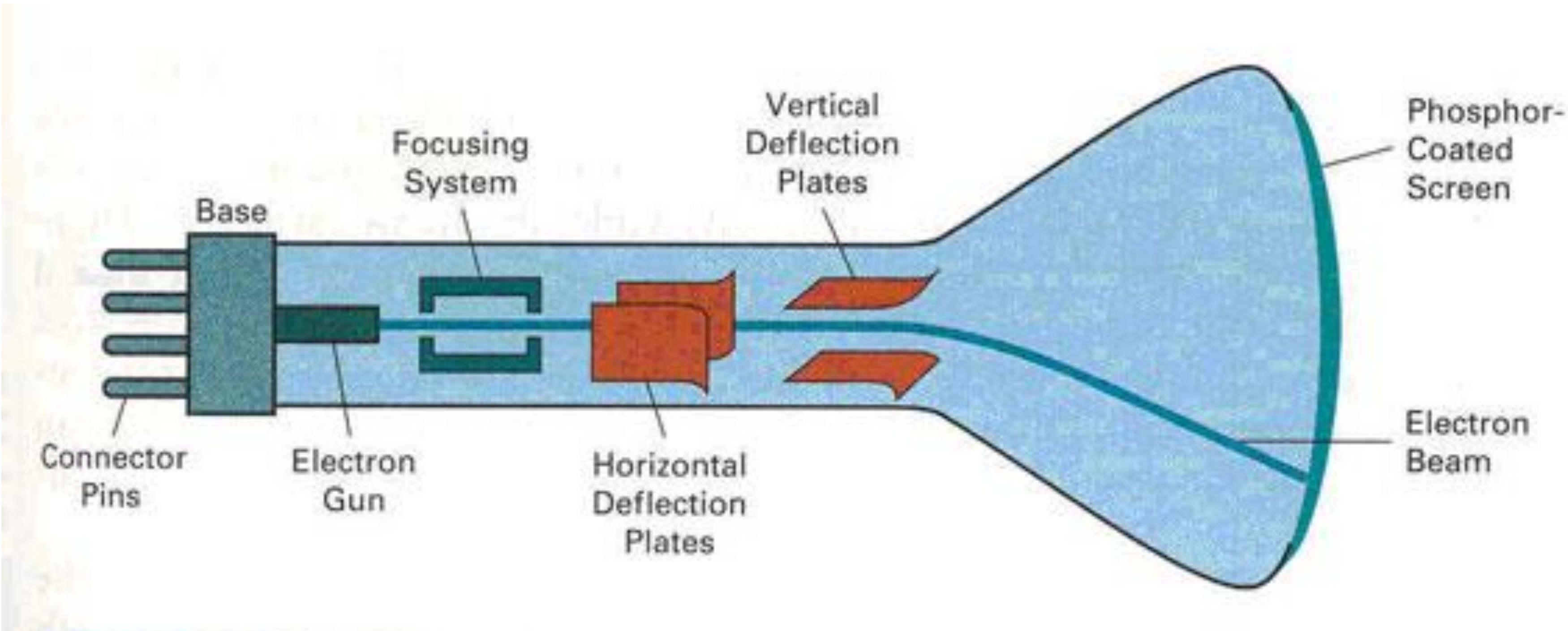
Focusing

- Additional focusing hardware is used in high-precision systems to keep the beam in focus at all screen positions
- The distance that the electron beam must travel to different points on the screen varies because the radius of curvature for most CRTs is greater than the distance from the focusing system to the screen center.
- Therefore, the electron beam will be focused properly only at the center of the screen.
- As the beam moves to the outer edges of the screen, displayed images become blurred.
- To compensate for this, the system can adjust the focusing according to the screen position of the beam.

Electrostatic deflection of the electron beam in a CRT

- Deflection of the electron beam can be controlled either with electric fields or with magnetic fields
- CRT are now commonly constructed with magnetic deflection coils mounted on the outside of the CRT envelope
- Two pairs of coils are used, with the coils in each pair mounted on opposite sides of the neck of the CRT envelope
  - One pair is mounted on the top and bottom of the neck
  - The other pair is mounted on opposite sides of the neck
- The magnetic, field produced by each pair of coils results in a transverse deflection force that is perpendicular both to the direction of the magnetic field and to the direction of travel of the electron beam.
- Horizontal deflection is accomplished with one pair of coils, and vertical deflection by the other pair.
- The proper deflection amounts are attained by adjusting the current through the coils.
- When electrostatic deflection is used, two pairs of parallel plates are mounted inside the CRT envelope.
- One pair of plates is mounted horizontally to control the vertical deflection, and the other pair is mounted vertically to control horizontal deflection

Electrostatic deflection of the electron beam in a CRT



Cathode-Ray Tubes

- When the electrons in the beam collide with the phosphor coating, they are stopped and their kinetic energy is absorbed by the phosphor.
  - Part of the beam energy is converted by friction into heat energy
  - The remainder causes electrons in the phosphor atoms to move up to higher quantum-energy levels.
- After a short time, the “excited” phosphor electrons begin dropping back to their stable ground state, giving up their extra energy as small quantums of Light energy.
- What we see on the screen is the combined effect of all the electron light emissions: a glowing spot that quickly fades after all the excited phosphor electrons have returned to their ground energy level
- The frequency (or color) of the light emitted by the phosphor is proportional to the energy difference between the excited quantum state and the ground state.

Different kinds of Phosphor: persistence

- Persistence is defined as the time it takes the emitted light from the screen to decay to one-tenth of its original intensity
- Lower persistence phosphors require higher refresh rates to maintain a picture on the screen without flicker
- A phosphor with low persistence is useful for animation
- A high-persistence phosphor is useful for displaying highly complex, static pictures
- Although some phosphors have a persistence greater than 1 second, graphics monitors are usually constructed with a persistence in the range from 10 to 60 microseconds.

Resolution

- *The maximum number of points that can be displayed without overlap on a CRT is referred to as the resolution*
  - **number of points per centimeter that can be plotted horizontally and vertically although it is often simply stated as the total number of points in each direction**
- The resolution of a CRT is dependent on
  - The type of phosphor
  - The intensity to be displayed
  - The focusing and deflection systems.
- Typical **resolution on high-quality systems is 1280 by 1024**, with higher resolutions available on many systems
- High resolution systems are often referred to as ***high-definition systems**.*
- *The physical* size of a graphics monitor is given as **the length of the screen diagonal**, with sizes varying from about 12 inches to 27 inches or more.
- A CRT monitor can be attached to a variety of computer systems, so the number of screen points that can actually be plotted depends on the capabilities of the system to which it is attached.

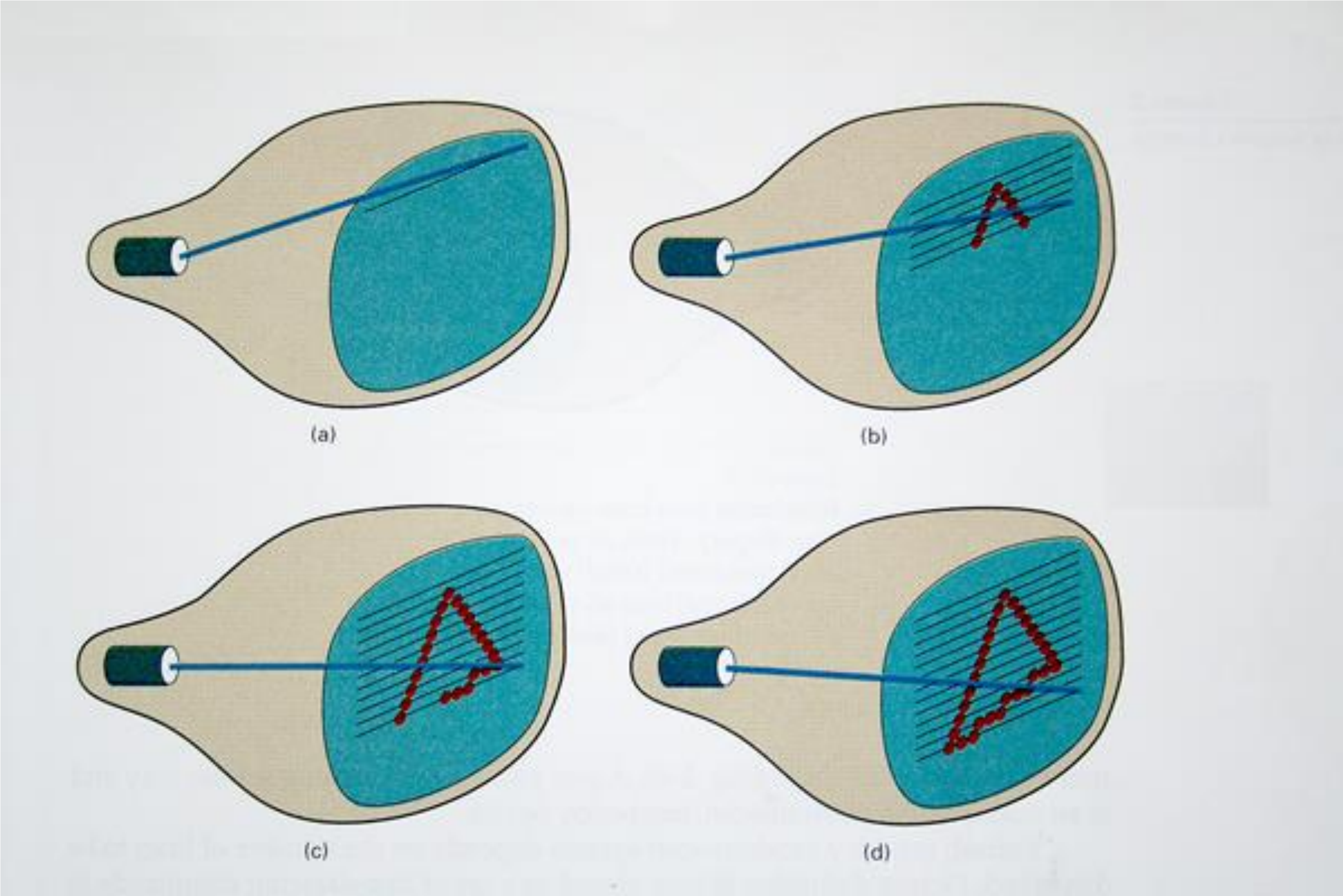
Aspect Ratio

- **The ratio of vertical points to horizontal points necessary to produce equal-length lines in both directions on the screen.**
- (Sometimes aspect ratio is stated in terms of
- the ratio of horizontal to vertical points)
- An aspect ratio of 3/4 means that a vertical line plotted with three points has the same length as a horizontal line plotted with four points

Raster Scan Display

- The electron beam is swept across the screen, one row at a time from top to bottom
  - The beam intensity is turned on and off to
  - Create a pattern of illuminated spots
- Picture definition is stored in a memory area called the refresh buffer or frame buffer
  - holds the set of intensity values for all the screen points
  - Stored intensity values are then retrieved from the refresh buffer and "painted" on the screen one row (scan line) at a time
  - Each screen point is referred to as a pixel or pel (shortened fonns of picture element).
- The capability of a raster-scan system to store intensity information for each screen point makes it well suited for the realistic display of scenes containing subtle shading and color patterns

Raster Scan Display

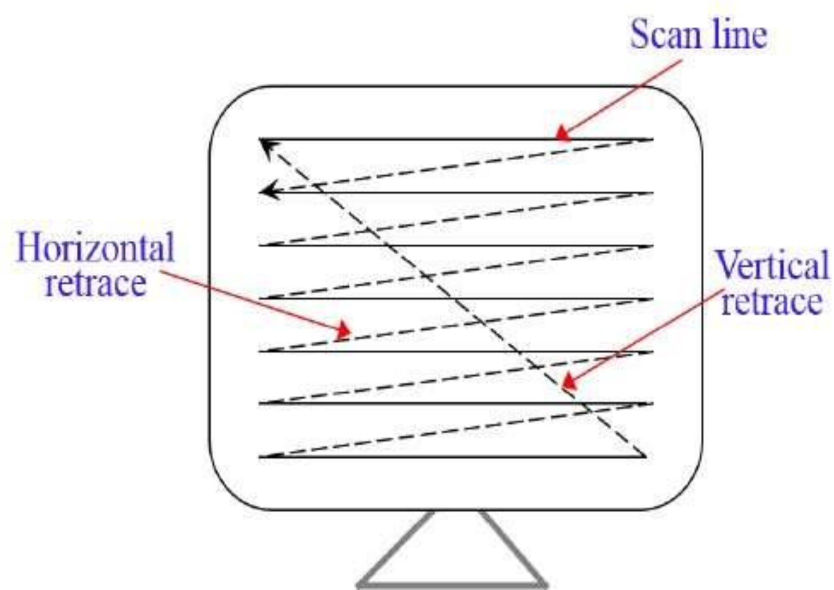


Raster Scan Display

- For black-and-white system (bilevel image)
  - a bit value of 1 indicates that the electron beam is to be turned on at that position
  - a value of 0 indicates that the beam intensity is to be off
- A system with 24 bits per pixel and a screen resolution of 1024 by 1024 requires 3 megabytes of storage for the frame buffer.
- On a black-and-white system with one bit per pixel, the frame buffer is commonly called a bitmap
- For systems with multiple bits per pixel, the frame buffer is often referred to as a pixmap

Raster Scan Display

- Refreshing - at the rate of 60 to 80 frames per second
  - refresh rates are described in units of cycles per second, or Hertz (Hz), where a cycle corresponds to one frame
- 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
- The return to the left of the screen, after refreshing each scan line, is called the horizontal retrace of the electron beam
- At the end of each frame (displayed in 1/80th to 1/60th of a second), the electron beam returns (vertical retrace) to the top left comer of the screen to begin the next frame



Raster Scan Display

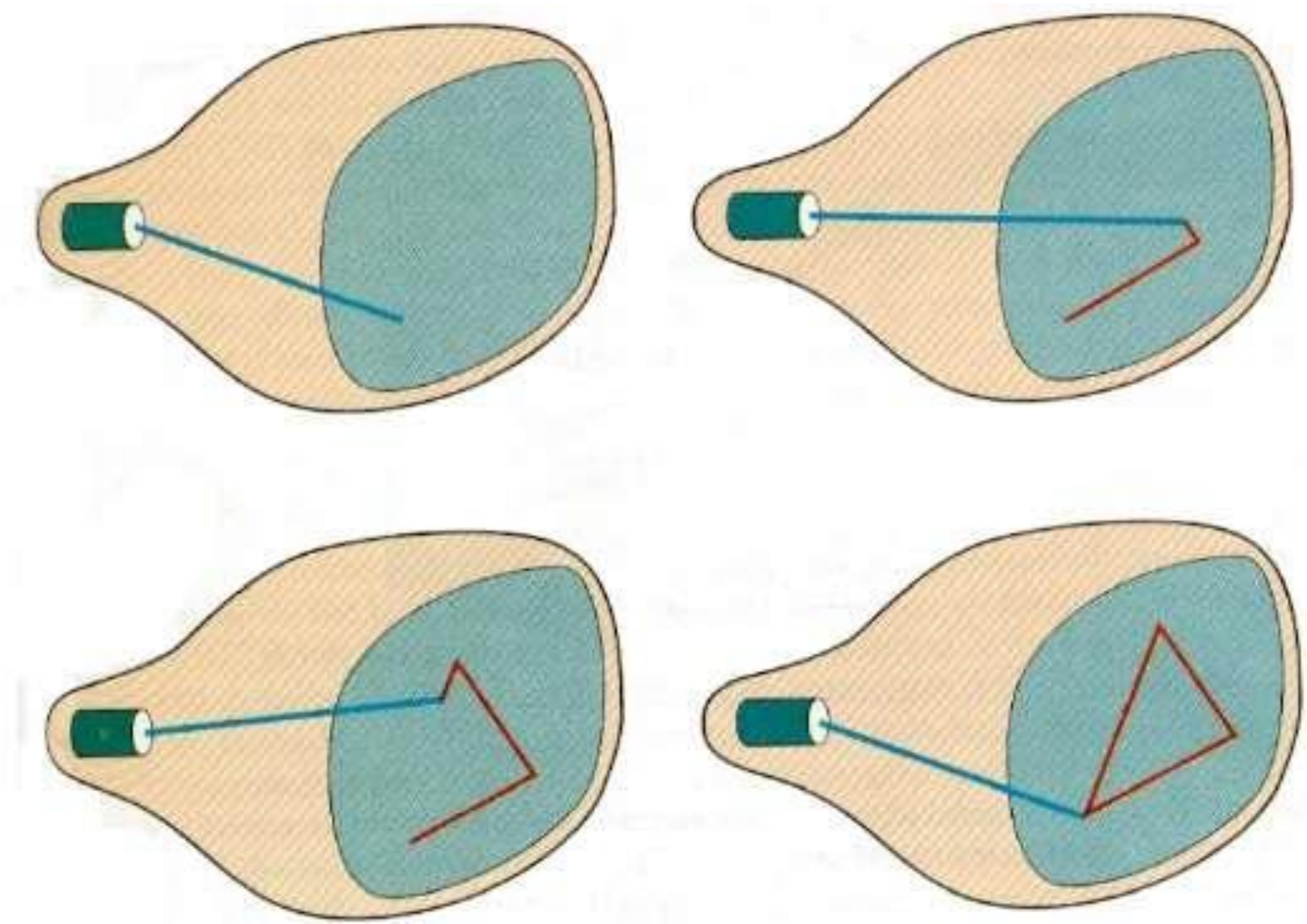
Interlacing:

- 1^{st} Pass- the beam sweeps across every other scan line from top to bottom
- 2^{nd} Pass: after the vertical retrace, the beam sweeps out the remaining scan lines
- 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 slower refreshing rates
- On an older, 30 frames-per-second, non-interlaced display, for instance, some flicker is noticeable.
- But with interlacing, each of the two passes can be accomplished in 1/60th of a second, which brings the refresh rate nearer to 60 frames per second
- This is an effective technique for avoiding flicker, providing that *adjacent scan lines contain similar display information*

Random Scan Display

- The electron beam directed only to the parts of the screen where a picture is to be drawn
- Random scan monitors draw a picture one line at a time
  - vector displays or stroke-writing or calligraphic displays
- The component lines of a picture can be drawn and refreshed by a random-scan system in any specified order
- Example: Pen Plotter

Random Scan Display



Random Scan Display

- Refresh rate: depends on the number of lines to be displayed.
- Picture definition stored as a set of line drawing commands in an area of memory referred to as the refresh display file, or display list, or display program, or refresh buffer
- Display a Picture: drawing each component line in turn
  - After all line drawing commands have been processed
  - The system cycles back to the first line command in the list
- Random-scan displays are designed to draw all the component lines of a picture 30 to 60 times each second.
- High quality vector systems are capable of handling approximately 100,000 "short" lines at this refresh rate
- When a small set of lines is to be displayed, each refresh cycle is delayed to avoid refresh rates greater than 60 frames per second
  - faster refreshing of the set of lines could burn out the phosphor

Random-scan vs. Raster -scan

- Random-scan systems:
  - designed for line drawing applications and cannot display realistic shaded scenes
  - generally have higher resolution than raster systems
  - produce smooth line drawings because the CRT beam directly follows the line path
- Raster-scan systems:
  - produces jagged lines that are plotted as discrete point sets

Color CRT Monitor

- Displays color pictures by using a combination of phosphors that emit different-colored light
- Combining the emitted light from the different phosphors
  - a range of colors can be generated
- The two basic techniques:
  - The beam-penetration method
  - The shadow-mask method

Color CRT Monitor: Beam Penetration

- Used with random-scan monitors
- Two layers of phosphor (red and green) are coated onto the inside of the CRT screen
- The displayed color depends on *how far the electron beam penetrates into the phosphor layers*
- A beam of slow electrons excites only the outer red layer
- A beam of very fast electrons penetrates through the red layer and excites the inner green layer
- At intermediate beam speeds, combinations of red and green light are emitted to show two additional colors, orange and yellow
- The speed of the electrons, and hence the screen color at any point, is controlled by the beam-acceleration voltage

Color CRT Monitor: Beam Penetration

- Inexpensive
- Only four colors are possible
- The quality of pictures is not as good as with other methods

Color CRT Monitor: Shadow Mask

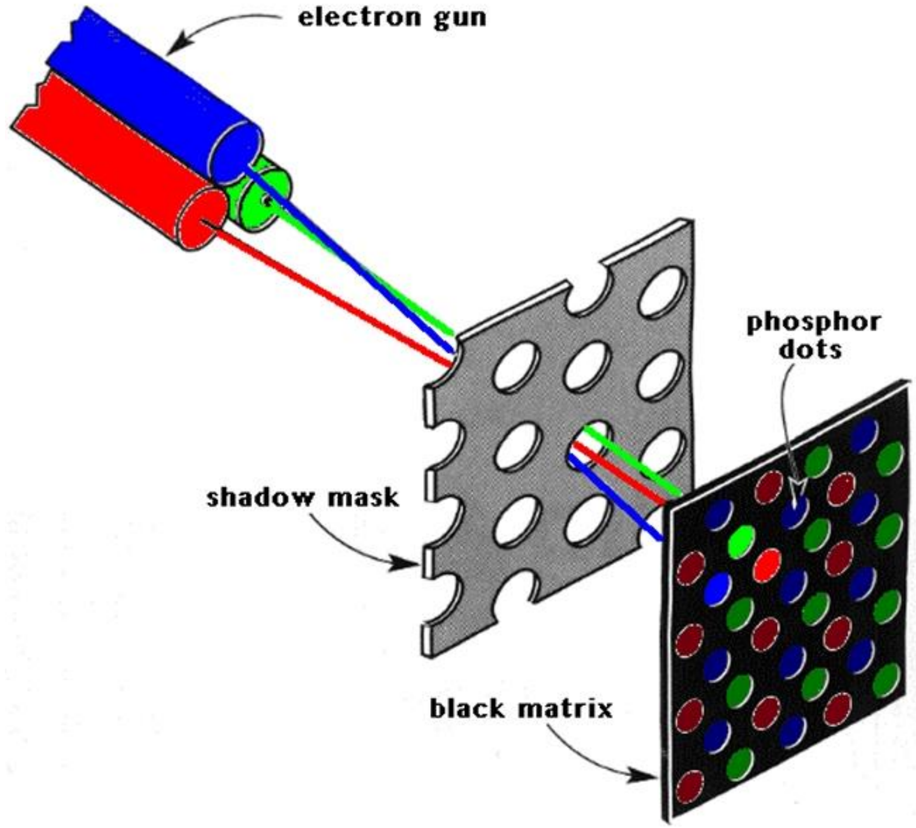
- Used in raster-scan systems (including color TV) because they produce a much wider range of colors
- Three phosphor color dots (Red, Green, Blue) at each pixel position
- Three electron guns -> one for each color dot
- A shadow-mask grid just behind the phosphor-coated screen

Color CRT Monitor: Shadow Mask

The delta-delta shadow-mask method - commonly used in color CRT systems

The three electron beams are deflected and focused as a group onto the shadow mask, which contains a series of holes aligned with the phosphor-dot patterns. When the three beams pass through a hole in the shadow mask, they activate a dot triangle, which appears as a small color spot on the screen.

The phosphor dots in the triangles are arranged so that each electron
beam can activate only its corresponding color dot when it passes through the shadow mask

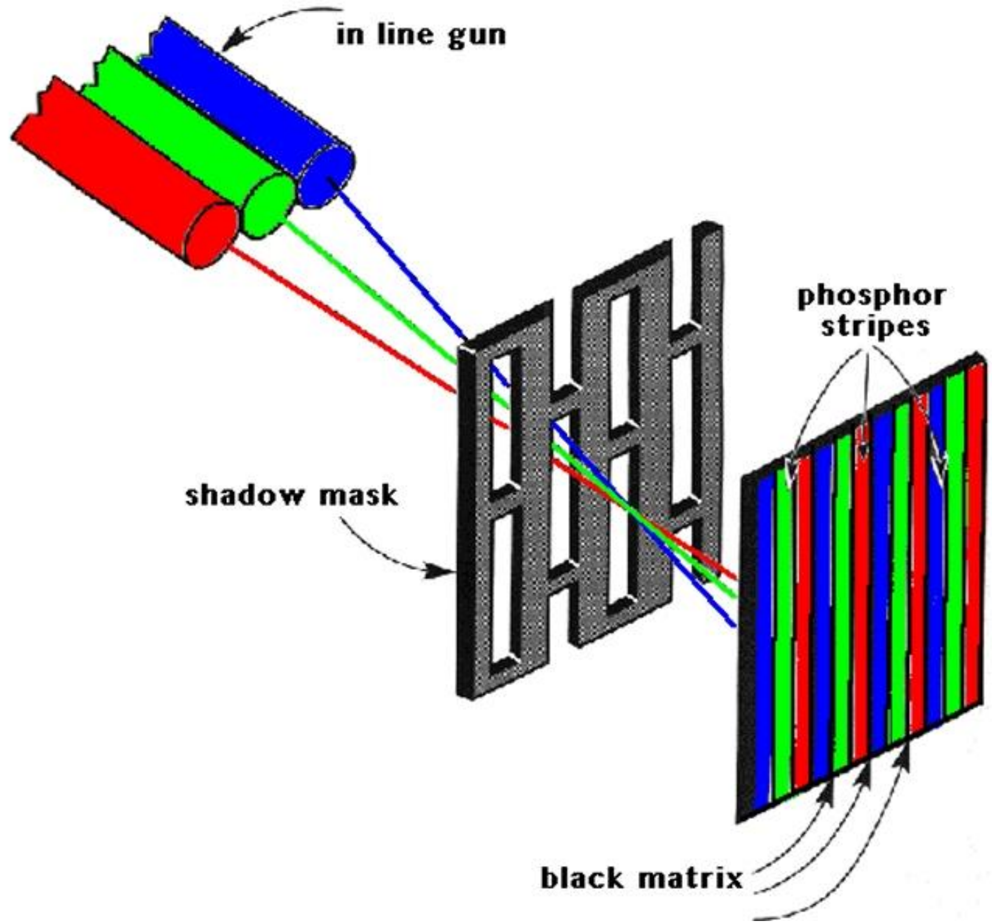


Color CRT Monitor: Shadow Mask

The in-line arrangement

Three electron guns, and the corresponding red-green-blue color dots on the screen, are aligned along one scan line instead of in a triangular pattern.

This in-line arrangement of electron guns is easier to keep in alignment and is commonly used in high-resolution color CRTs



Color CRT Monitor: Shadow Mask

- Color variations in a shadow-mask CRT
  - by varying the intensity levels of the three electron beams
- By setting intermediate intensity levels for the electron beams
  - several million different colors to be generated

High-quality raster-graphics systems have 24 bits per pixel in the frame buffer, allowing 256 voltage settings for each electron gun and nearly 17 million color choices for each pixel. An RGB color system with 24 bits of storage per pixel is generally referred to as a full-color system or a true-color system.

Direct-View Storage Tubes (DVST)

- Stores the picture information as a charge distribution just behind the phosphor-coated screen
- Two electron guns are used
- Primary gun: store the picture pattern;
- Second gun: maintains the picture display
- **Advantages:** no refreshing is needed, very complex pictures can be displayed at very high resolutions without flicker
- **Disadvantages:** erasing and redrawing process can take several seconds for a complex picture.
- *Storage displays have been largely replaced by raster systems*

Flat-Panel Displays

- Reduced volume, weight, and power requirements compared to a CRT, thinner then CRT
- Two categories: emissive displays and non-emissive displays
- Emissive Displays:
  - Convert electrical energy into light
  - Plasma panels, thin-film electroluminescent displays, and Light-emitting diodes
- Non-emissive Displays:
  - Use optical effects to convert sunlight or light from some other source into graphics patterns
  - Liquid-crystal device

Plasma Panel/ Gas Discharge Displays

- Filling the region between two glass plates with a mixture of gases that usually includes neon
- A series of vertical conducting ribbons is placed on one glass panel
- A set of horizontal ribbons is built into the other glass panel
- Firing voltages applied to a pair of horizontal and vertical conductors
  - the gas at the intersection of the two conductors to break down into a glowing plasma of electrons and ions
- Picture definition is stored in a refresh buffer
- The firing voltages are applied to refresh the pixel positions (at the intersections of the conductors) 60 times per second
- Alternating-current methods are used to provide faster application of the firing voltages, and thus brighter displays
- Separation between pixels is provided by the electric field of the conductors
- Disadvantages: strictly monochromatic devices
  - now capable of displaying color and grayscale

Thin-film electroluminescent displays

- The region between the glass plates is filled with a phosphor, such as zinc sulfide doped with manganese, instead of a gas
- When a sufficiently high voltage is applied to a pair of crossing electrodes
  - The phosphor becomes a conductor in the area of the intersection of the two electrodes
  - Electrical energy is then absorbed by the manganese atoms
  - which then release the energy as a spot of light
- **Disadvantages:**
  - require more power
  - good color and gray scale displays are hard to achieve

Light-emitting diode (LED)

- A matrix of diodes is arranged to form the pixel positions in the display
- Picture definition is stored in a refresh buffer
- Information is read from the refresh buffer
- Converted to voltage levels that are applied to the diodes to produce the light patterns in the display

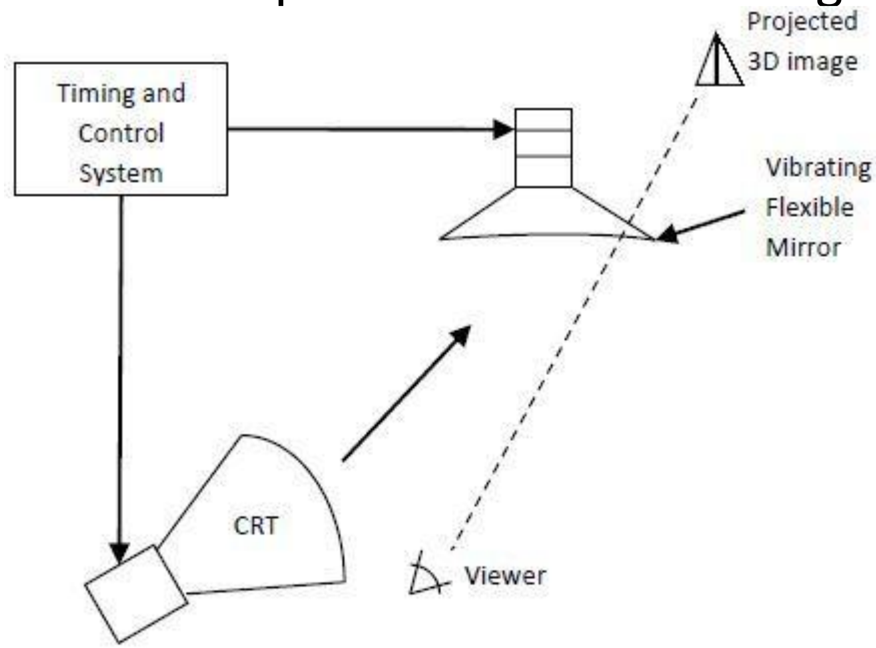
Liquid Crystal Displays (LCDs)

- Commonly used in small systems
  - Calculators and portable, laptop computers
- Non-emissive devices
- Produce a picture
  - by passing polarized light from the surroundings
  - from an internal light source through a liquid-crystal material that can be aligned to either block or transmit the light

Three Dimensional Viewing Devices

- This method display using computer generated scenes.
- It may display object by three-dimensional views.
- The graphics monitor which are display three-dimensional scenes is devised using a technique that reflects a CRT image from a vibrating flexible mirror.
- Vibrating mirror changes its focal length due to vibration which synchronized with the display of an object on CRT.
- Each point on the object reflected from the mirror into the spatial position corresponding to a distance of that point. From a viewing position.

Very good example of this system is GENISCO SPACE GRAPH system. Which use the vibrating mirror to project 3D objects into a 25 cm by 25 cm by 25 cm volume. This system is also capable to show 2D cross section at the different depth.



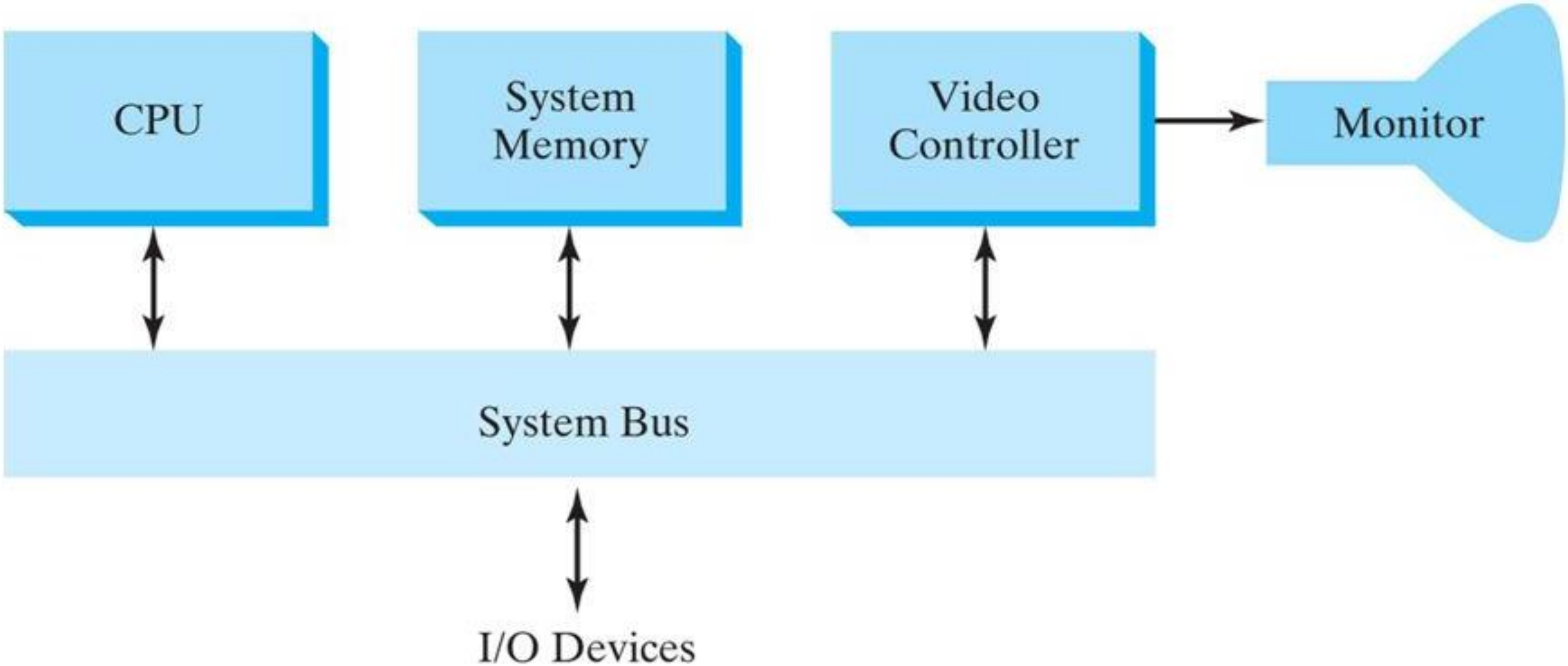
Stereoscopic System

- Way of representing 3D objects
- Does not produce true 3D image
- Provides a 3D effect by presenting a different view to each eye of an observer so that scenes do appear to have depth
- **Stereoscopic Projection:** Two views of a scene generated from a viewing direction corresponding to each eye (left and right)
- We can construct the two views as computer-generated scenes with different viewing positions, or we can use a stem camera pair to photograph some object or scene
- Display each of the two views with a raster system on alternate refresh cycles

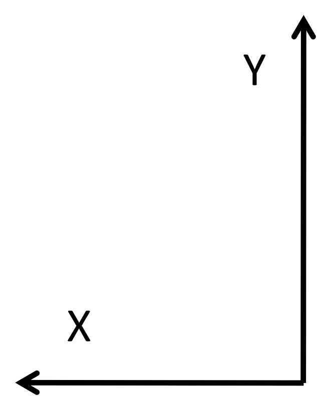
Virtual Reality System

- Stereoscopic viewing is also a component in virtual-reality systems
  - where users can step into a scene and interact with the environment
- A headset containing an optical system to generate the stereoscopic views is commonly used in conjunction with interactive input devices to locate and manipulate objects in the scene
- A sensing system in the headset keeps track of the viewer's position, so that the front and back of objects can be seen as the viewer "walks through" and interacts with the display
- Can also be viewed with stereoscopic glasses and a video monitor, instead of a headset -> lower cost
- The tracking device is placed on top of the video display and is used to monitor head movements so that the viewing position for a scene can be changed as head position changes

Raster-Scan System



- A fixed area of the system memory is reserved for the frame buffer
- The video controller is given direct access to the frame-buffer memory
- Frame-buffer locations, and the corresponding screen positions, are referenced in Cartesian coordinates



Video Controller- Refreshing

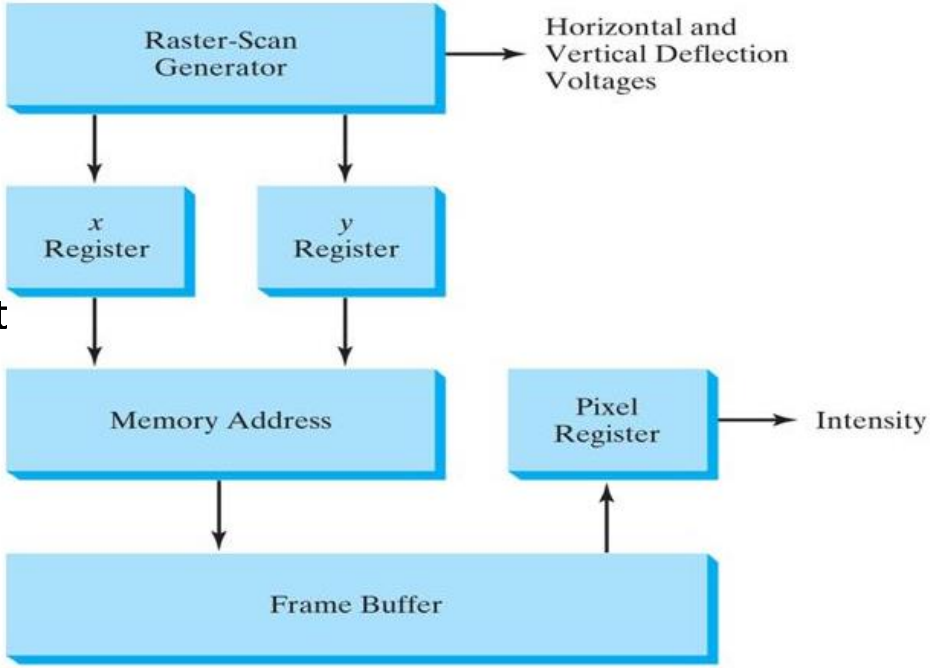
•Two registers are used to store the coordinates of the screen pixels

- •x register is set to 0
- •y register is set to y_{max}

•The value stored in the frame buffer for this pixel position is then retrieved and used to set the intensity of the CRT beam

•x register is incremented by 1, and the process repeated for the next pixel on the top scan line

•This procedure is repeated for each pixel along the scan line.



•After the last pixel on the top scan line has been processed

- •x register is reset to 0 and the y register is decremented by 1

•Pixels along this scan line are then processed in turn, and the procedure is repeated for

•each successive scan line

•After cycling through all pixels along the bottom scan line (y = 0), the video controller resets the registers to the first pixel position on the top scan line and the refresh process starts over.

Video Controller- To speed up Refreshing

- Refreshing at the rate of 60 frames per second
- The cycle time is too slow
- To speed up pixel processing
  - The video controllers can *retrieve multiple pixel values from the refresh buffer on each pass*
  - The multiple pixel intensities are then stored in a separate register and used to control the CRT beam intensity for a *group of adjacent pixels*
  - When that group of pixels has been processed,
    - The next block of pixel values is retrieved from the frame buffer

Video Controller- Several Roles

- Two frame buffers:
  - One buffer for refreshing
  - Other filled with intensity values
  - Then the two buffers can switch roles.
- Fast mechanism-for generating *real-time animations*
  - different views of moving objects can be successively loaded into the refresh buffers
- Transformation: Areas of the screen can be enlarged, reduced, or moved from one location to another during the refresh cycles
  - Video controller contains a lookup table
  - The pixel values in the frame buffer are used to access the lookup table instead of controlling the CRT beam intensity directly
- Mixing the frame-buffer image with an input image from a television camera or other input device

Color Lookup Table

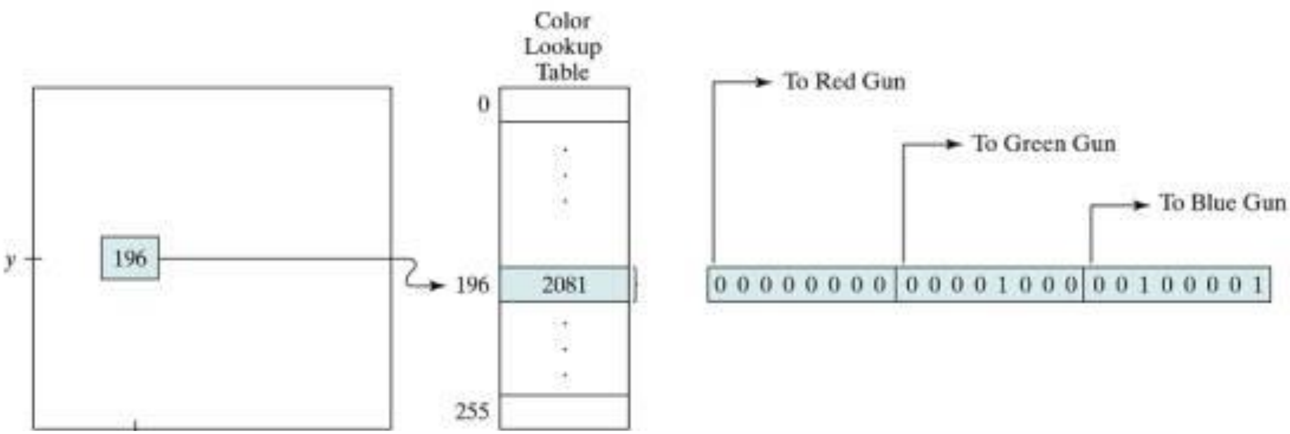


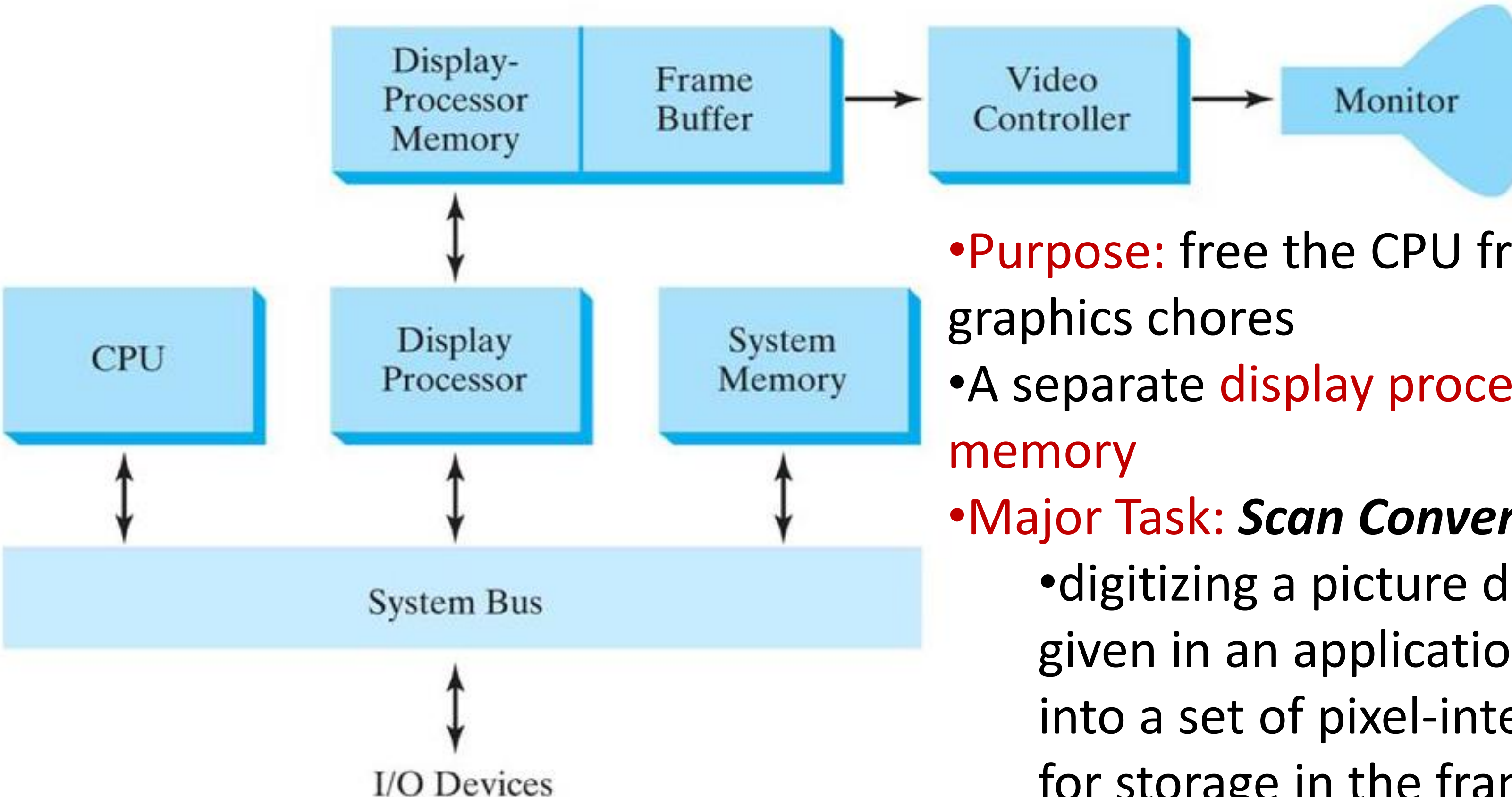
TABLE 4-1

THE EIGHT RGB COLOR CODES FOR A THREE-BIT PER PIXEL FRAME BUFFER

	Stored Color Values in Frame Buffer			
Color Code	*RED*	*GREEN*	*BLUE*	*Displayed Color*
0	0	0	0	Black
1	0	0	1	Blue
2	0	1	0	Green
3	0	1	1	Cyan
4	1	0	0	Red
5	1	0	1	Magenta
6	1	1	0	Yellow
7	1	1	1	White

- 24-bits per entry accessed from a frame buffer, 8 bits per pixel
- Pixel value 196 stored at (x,y) position references the location in the table containing a value 2081
- Each 8-bit segment of this entry controls the intensity level of one of the three electron guns in an RGB monitor.

Display Processor/ Graphics Controller/ Display Coprocessor



- Purpose: free the CPU from the graphics chores
- A separate display processor memory
- Major Task: ***Scan Conversion***
    - digitizing a picture definition given in an application program into a set of pixel-intensity values for storage in the frame buffer
    - Straight line segment, curved line, polygon outline, characters (rectangular grid/ curved outlines)

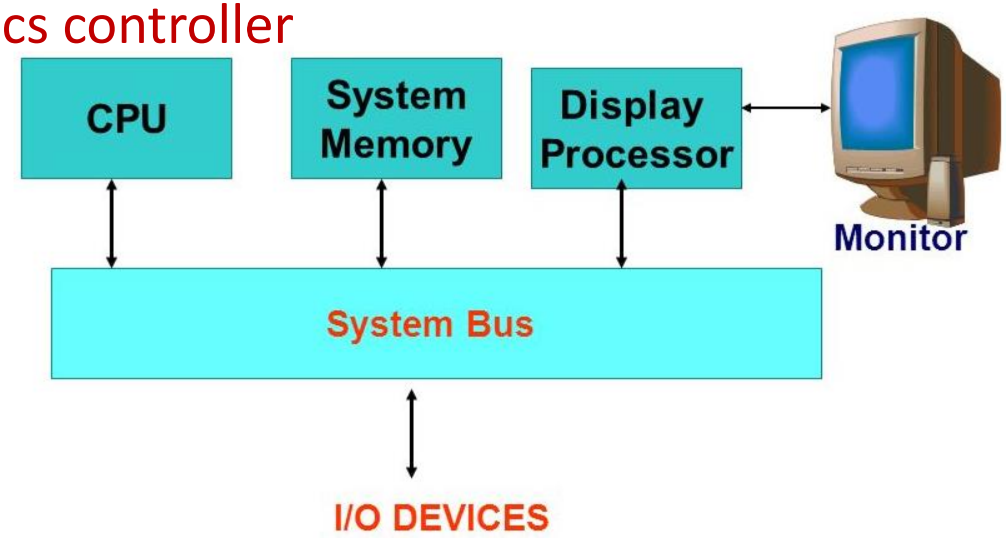
Display Processor - operation

- Generating various line styles (dashed, dotted,
- or solid), displaying color areas, and performing certain transformations and manipulations on displayed objects
- Designed to interface with interactive input devices such as a mouse
- To reduce memory requirements
  - organizing the frame buffer as a linked list and encoding the intensity information *(run-length encoding)*
  - To encode the raster as a set of rectangular areas *(cell encoding)*
- **Disadvantage:** when runs decreases

Random-Scan System

- An application program is input and stored in the system memory along with a
- graphics package
- Graphics commands in the application program are translated by the graphics package into a display file stored in the system memory
- This display file is then accessed by the display processor to refresh the screen
- The display processor cycles through each command in the display file program once during every refresh cycle
- Sometimes the display processor in a random-scan system is referred to as a display processing unit or a graphics controller

A scene is then drawn one line at a time by positioning the beam to fill in the line between specified endpoints



Input Devices

- Keyboards
- Mouse
- Trackball and Spaceball
- Joysticks
- Data Glove
- Digitizers
- Image Scanners
- Touch Panels
- Light Pens
- Voice Systems

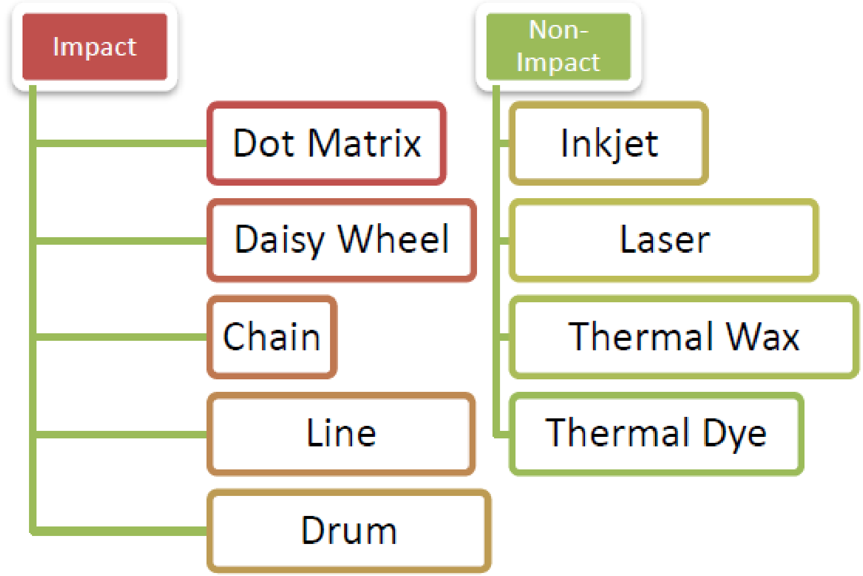
Hard Copy Devices

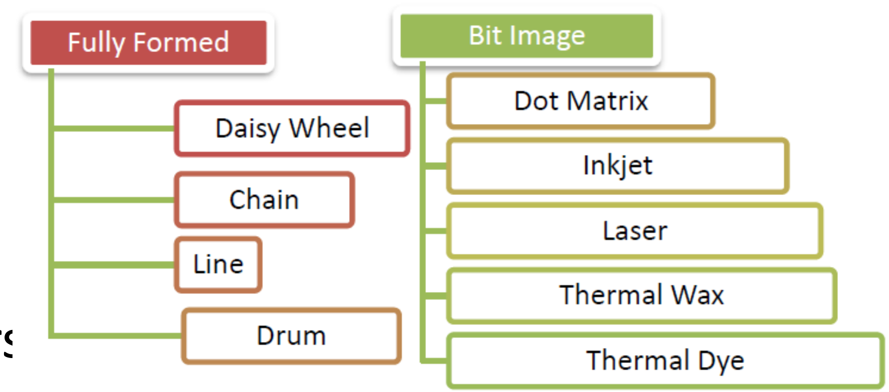
- **Printer**

Impact Printers: there exists a mechanical contact between print head and paper. Print head is the part of the printer that resembles a hammer and is responsible for transferring the ink to the paper in the form of required characters. Impact printer contains an individual print head for each character.

Non-Impact printers: there exists no mechanical contact between the print head and paper. These printers spray ink on the paper with the help of a nozzle. The most popular ones are ink-jet printers and laser printers.

- **Pen Plotter**





Graphics Software

- **Graphical Kernel System (GKS)**
- **PHIGS (Programmer's Hierarchical Interactive Graphics standard)**

- Standardization for device interface methods is given in the Computer Graphics Interface (CGI) system
- The Computer Graphics Metafile (CGM) system specifies standards for archiving and transporting pictures.

Some More Terms

- **Apixmap:** For systems with multiple bits per pixel, the frame is called as a apixmap.
- *Refresh rate> phosphor’s persistence -> moving object becomes blurred*
- *Refresh rate< phosphor’s persistence -> flickering*
- Dot Pitch: It is defined as the measurement of the diagonal distance between two liked-colored (RGB) pixels on a display screen. (0.25mm to 0.40 mm; 0.31mm -> clear image)
  - Smaller dot pitch -> higher resolution
- Image resolution: pixel spacing
- Screen resolution: no of pixels in the horizontal and vertical directions on the screen
- Bit Depth/ Color Depth: number of bits assigned to each pixel in the image