

Comp 410/510

Computer Graphics
Spring 2023

Introduction to Graphics Systems

Computer Graphics

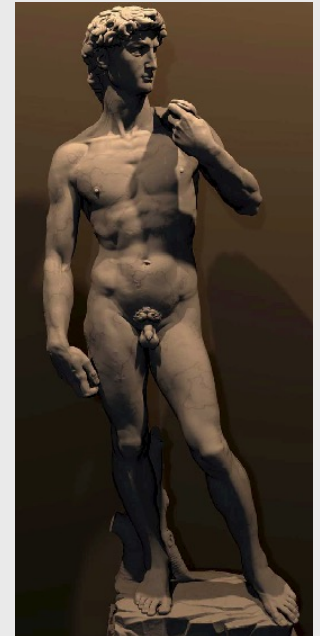
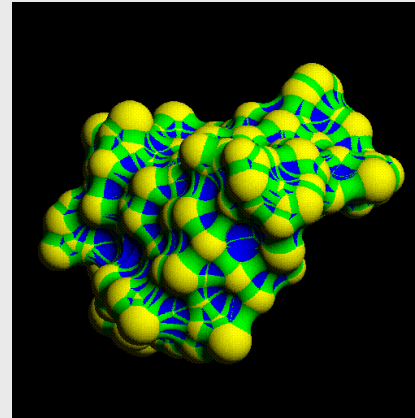
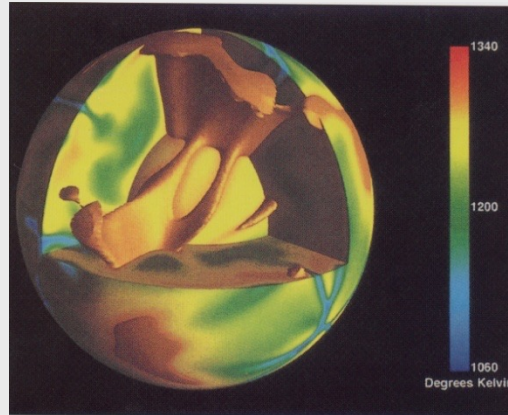
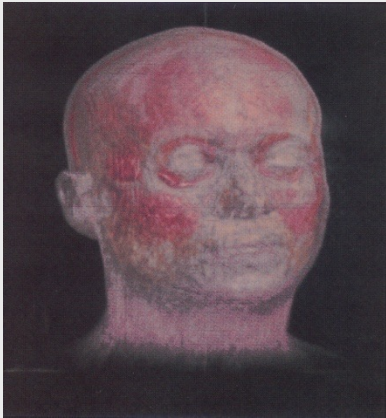
- **Computer graphics** deals with all aspects of 'creating' images with a computer
 - Hardware (PC with graphics card)
 - Software (API: OpenGL, Java3D, DirectX, Vulkan, Metal, etc)
 - Applications
 - Display of information
 - Design
 - Simulation and animation
 - User interfaces
 - Video games
 - etc.

This course is about

- implementation of graphics software API and
- writing graphics applications using **shader-based OpenGL**
- fundamentals and basic notions of computer graphics

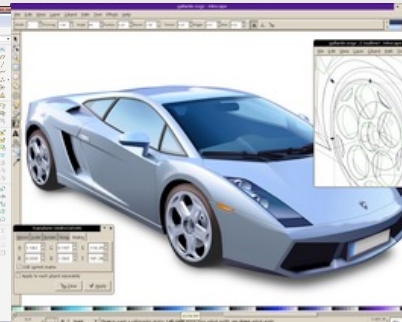
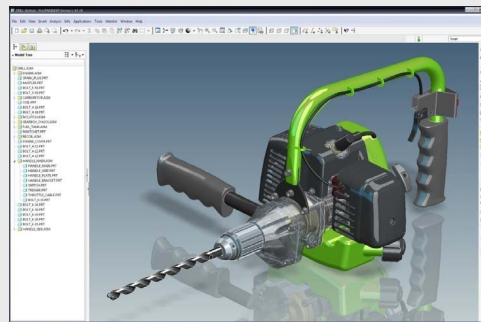
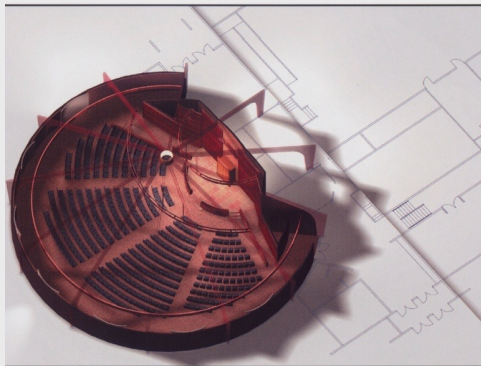
Display of Information

- Medical applications (CT, MRI, ultrasound, etc.)
- Fluid flow
- Molecular biology
- Cultural heritage
- E-commerce, publicity, digital catalog creation
- etc



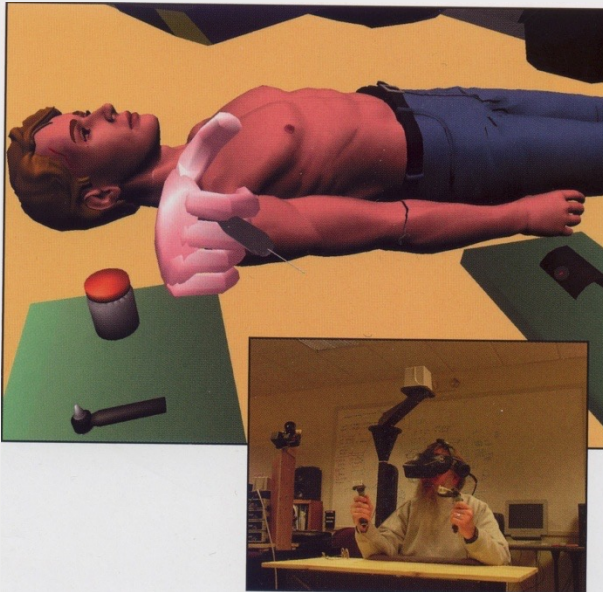
Design

- Architecture
- Design of mechanical parts (CAD systems)
- 3D printers
- VLSI circuits



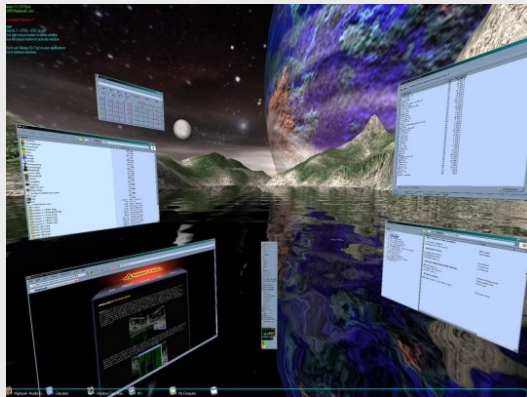
Simulation & Animation

- Simulators
- Animation movies
- Games
- Virtual reality

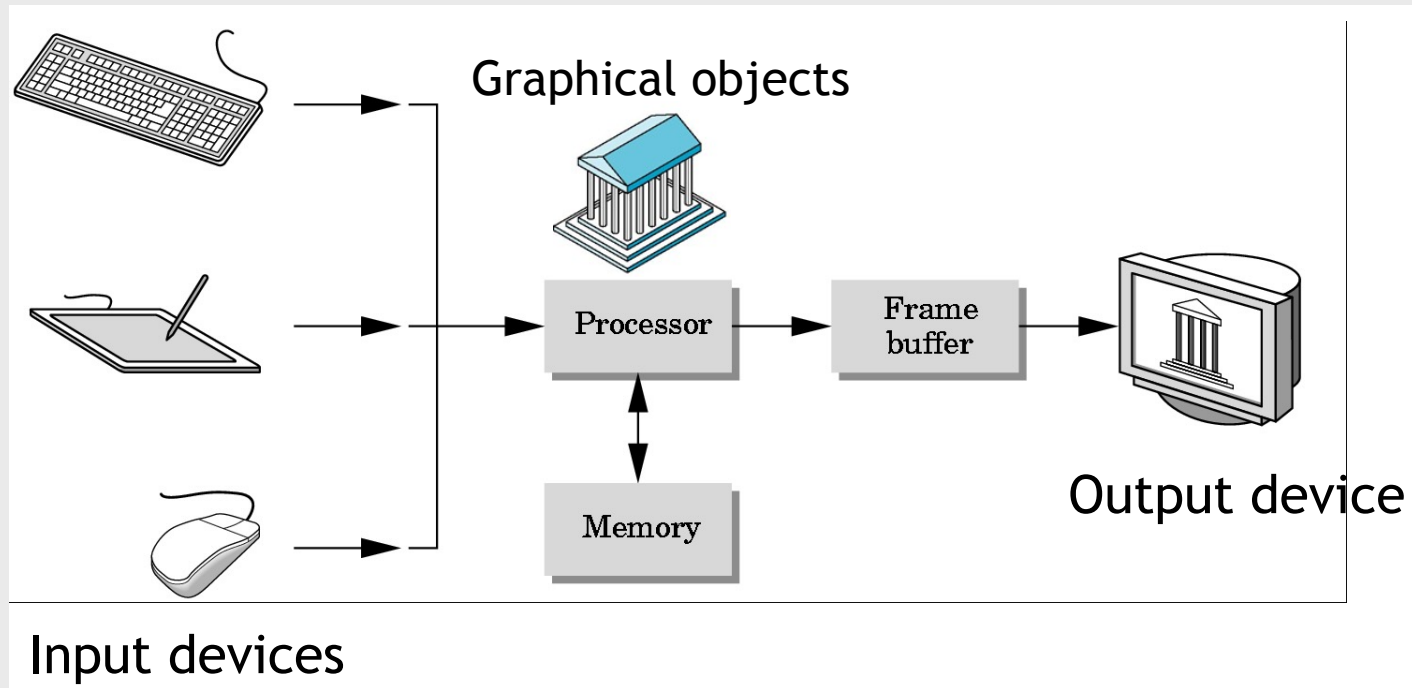


User Interfaces

- Most common: X window system, Microsoft Windows, MacOS, iOS, etc.
- Mostly graphics-based and 2D (windows, widgets, images, etc)
- More sophisticated graphical interfaces, possibly in 3D, are also possible



Basic Graphics System



Input devices are used to capture user input and provide a way for users to interact with the graphical objects displayed on the screen.

Basic Graphics System

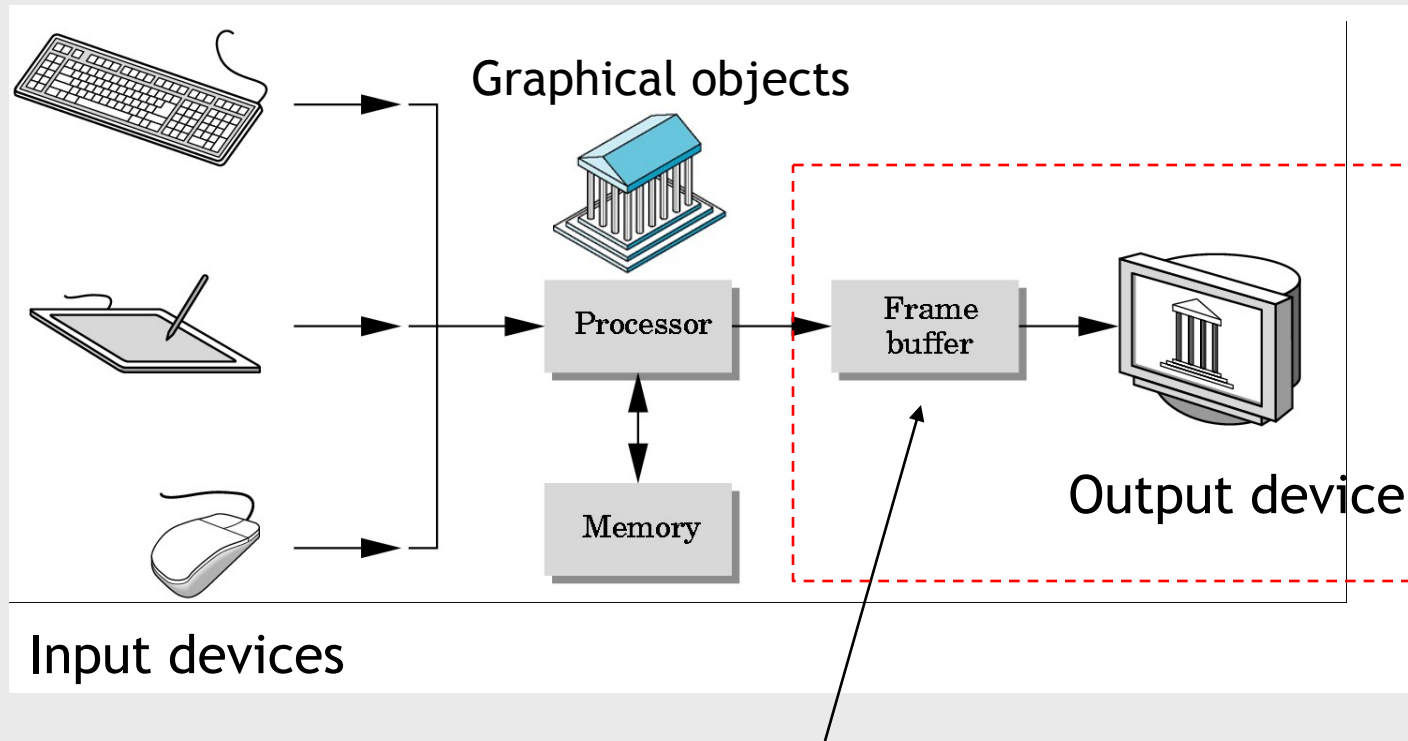
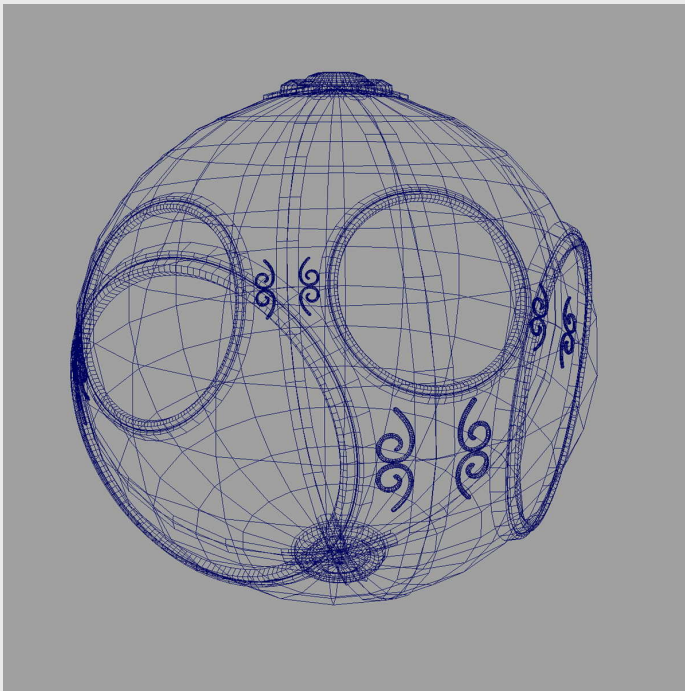


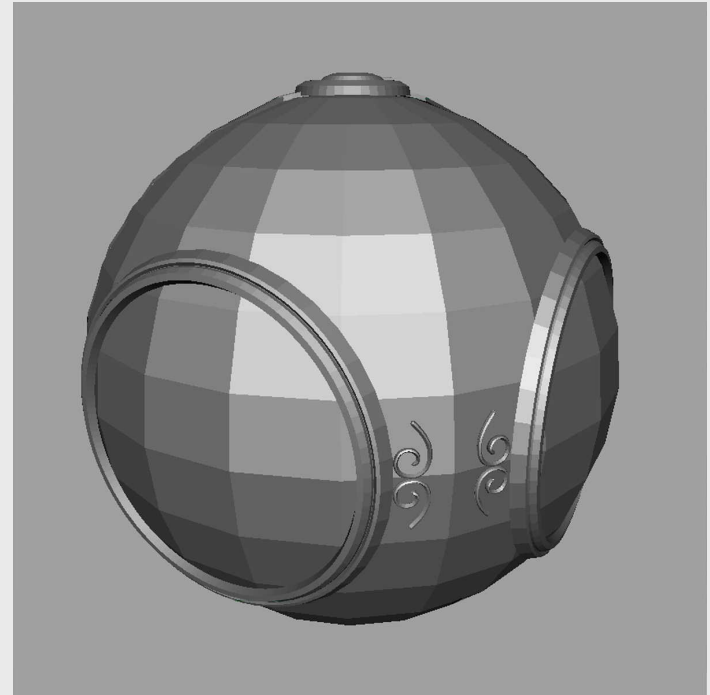
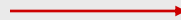
Image is formed in **Frame Buffer**
via the process **Rendering**

Rendering

- Allows us to go from graphical primitives (points, lines, polygons and wireframes) to pixels (e.g., filled polygons)

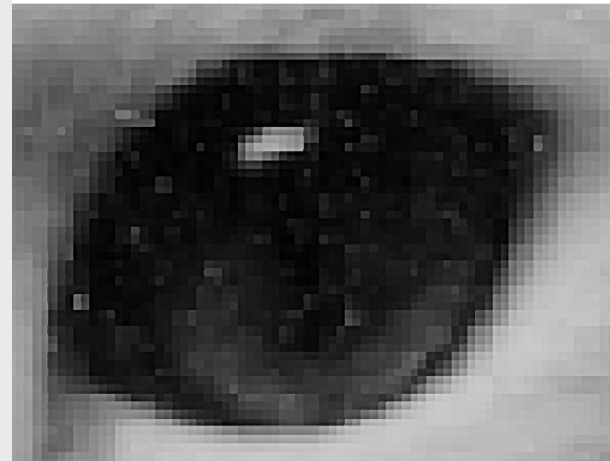
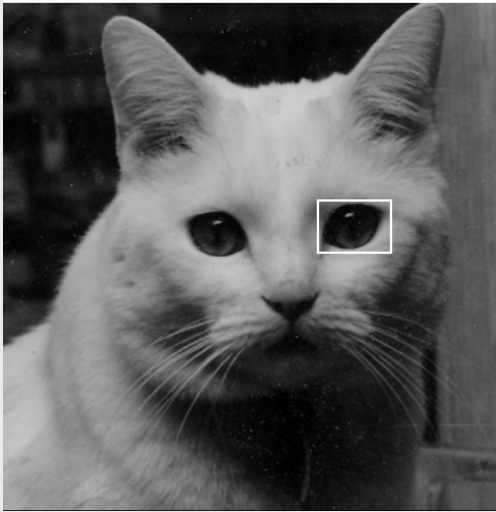


rendering



Raster Graphics

- Image is produced as an array (the *raster*) of picture elements (*pixels*) in the *frame buffer* (usually a DRAM in the video card)



- Frame buffer depth: # of bits used for each pixel
- Color buffer ~ Frame buffer: True color: 24-bit
- Resolution: # of pixels in frame buffer

Frame Buffer

Frame buffer can be thought of as computer memory organized as a two-dimensional array with each (x,y) addressable location corresponding to one pixel.

Bit Planes (or *Bit Depth*) is the number of bits corresponding to each pixel.

A typical frame buffer resolution can be

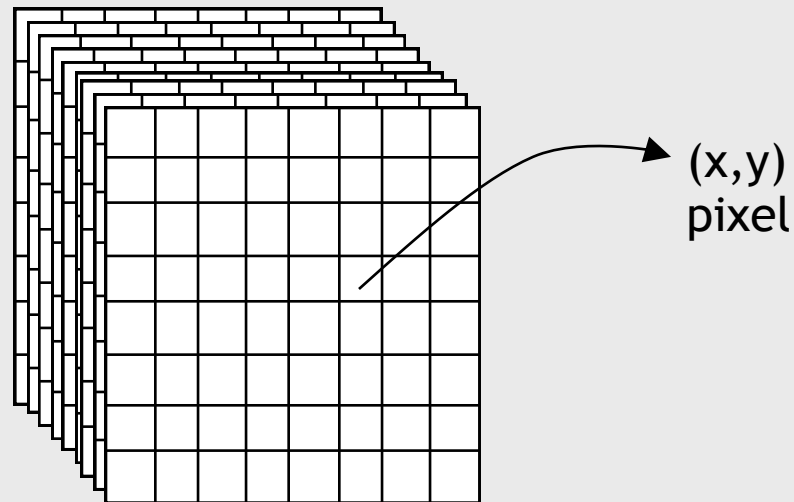
640 x 480 x 8

1280 x 1024 x 8

1280 x 1024 x 24

1920 x 1080 x 24

4096 by 2160 x 24

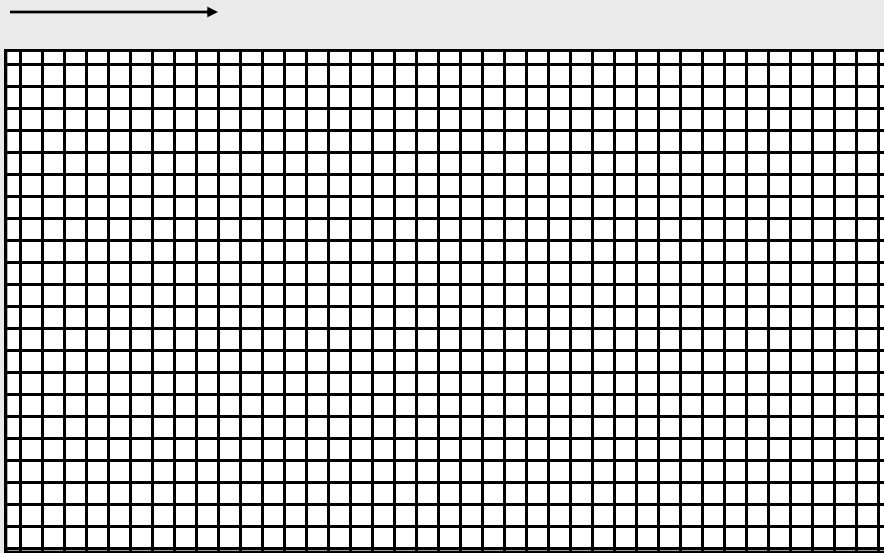


Basic Terminology

RASTER: A rectangular array of points or dots (image)

PIXEL: One dot or picture element of the raster

SCAN LINE: A row of pixels



RASTER SCAN ORDER:

Time-sequential pattern to draw or transmit pixels that form the image

Displays

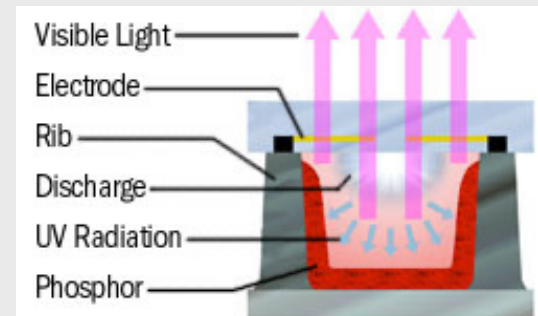
- **Emissive displays:**
 - Convert electrical energy into light
- **Non-emissive displays:**
 - Convert light from some other source into graphic patterns.

Emissive Displays

Convert electrical energy into light



- Cathode ray tube (CRT)
- Plasma panels (gas-discharge display)
- Light-emitting diodes (LED)

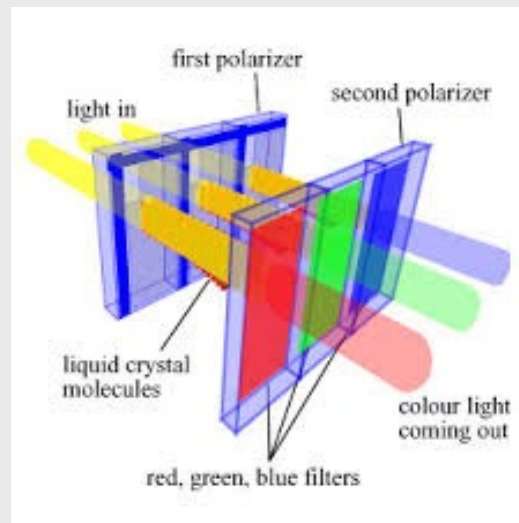


Plasma panels:

1. Charge causes the gas in the cell to emit ultraviolet light,
2. which causes the phosphor to emit color.
3. Amount of charge determines the intensity
4. Combination of different intensities of red, green and blue produces all colors required.

Non-Emissive Displays

- Convert light from some other source into graphic patterns.
- Liquid-crystal device (LCD):



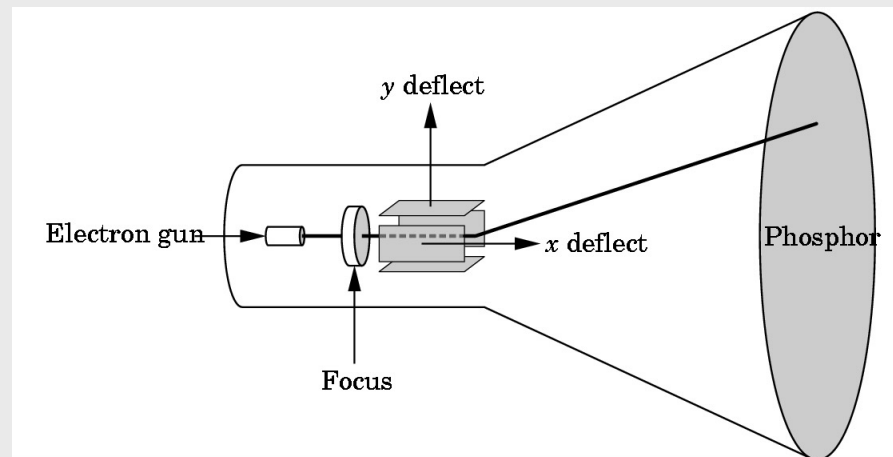
- Amount of voltage applied to liquid crystal molecules in each cell controls the amount of light passing through and illuminates the corresponding pixel at varying levels.
- Color LCDs contain three cells for each pixel; each cell uses an appropriate filter to get red, green or blue color.

CRT (Cathode-Ray Tube) Display (before millennium)



Cathode Ray - beam of electrons

- emitted by an electron gun,
- accelerated by a high positive voltage near the face of the tube,
- forced into a narrow stream by a focusing system,
- directed toward a point on the screen by the magnetic field generated by the deflection coils,
- hit onto the phosphor-coated screen.
- Phosphor emits visible light, whose intensity depends on the number of electrons striking on the screen
- Electron beam traces over screen in raster scan order



Photon
excitation decays
very fast

Properties of the CRT

- **Phosphor Persistence (PP)**
 - The light output decays exponentially with time.
 - Low persistence -> good for animation
 - High persistence -> good for static picture with high complexity
 - Typical range: 10ms - 60ms
- **Refresh rate (RR)**
 - Number of times per second the image is redrawn (e.g., 60 or higher)
 - Should be fast enough to avoid flickering due to light output decay
 - Should be slower than the speed of electron beam scanning hardware
- **Resolution**
 - The maximum number of points that can be displayed without overlap
 - e.g., HD 1280 * 720 pixels
- **Color**
 - Color CRT uses three electron guns, each targeting a separate dot on a phosphor triad

Display Scan Technology

Vector display (old)

- Image is composed of drawn **lines** (random scan)

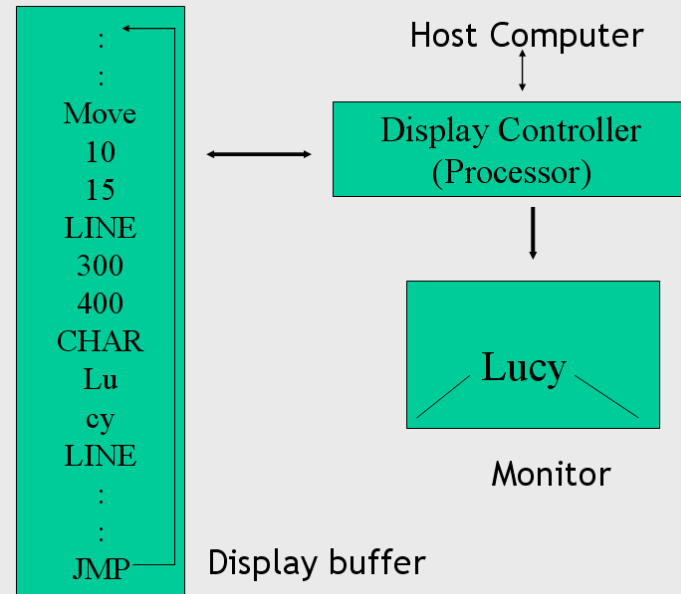
Raster display (current)

- Image is composed of **pixels** (scan line order)

Vector Display

Vector display (1960s)

- Vector system consists of:
 - display processor (controller),
 - display buffer (memory),
 - CRT monitor

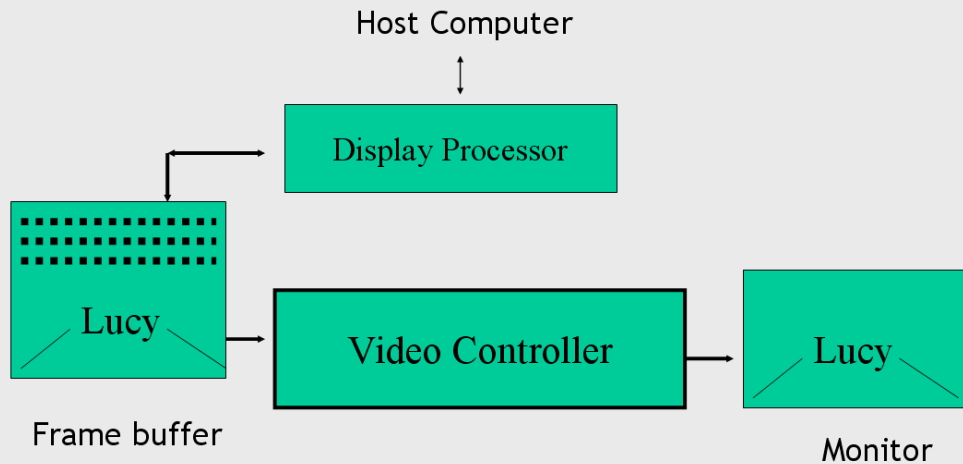


- The buffer stores the computer-produced *display list* or *display program*
- Display program contains point-plotting commands with (x, y, z) endpoint coordinates
- The commands for plotting are interpreted by the display processor
- The principle of vector system is *random scan*:
 - The beam is deflected from endpoint to endpoint, as dictated by the order of the display command
- Display needed to be refreshed (e.g., 30Hz)

Raster Display

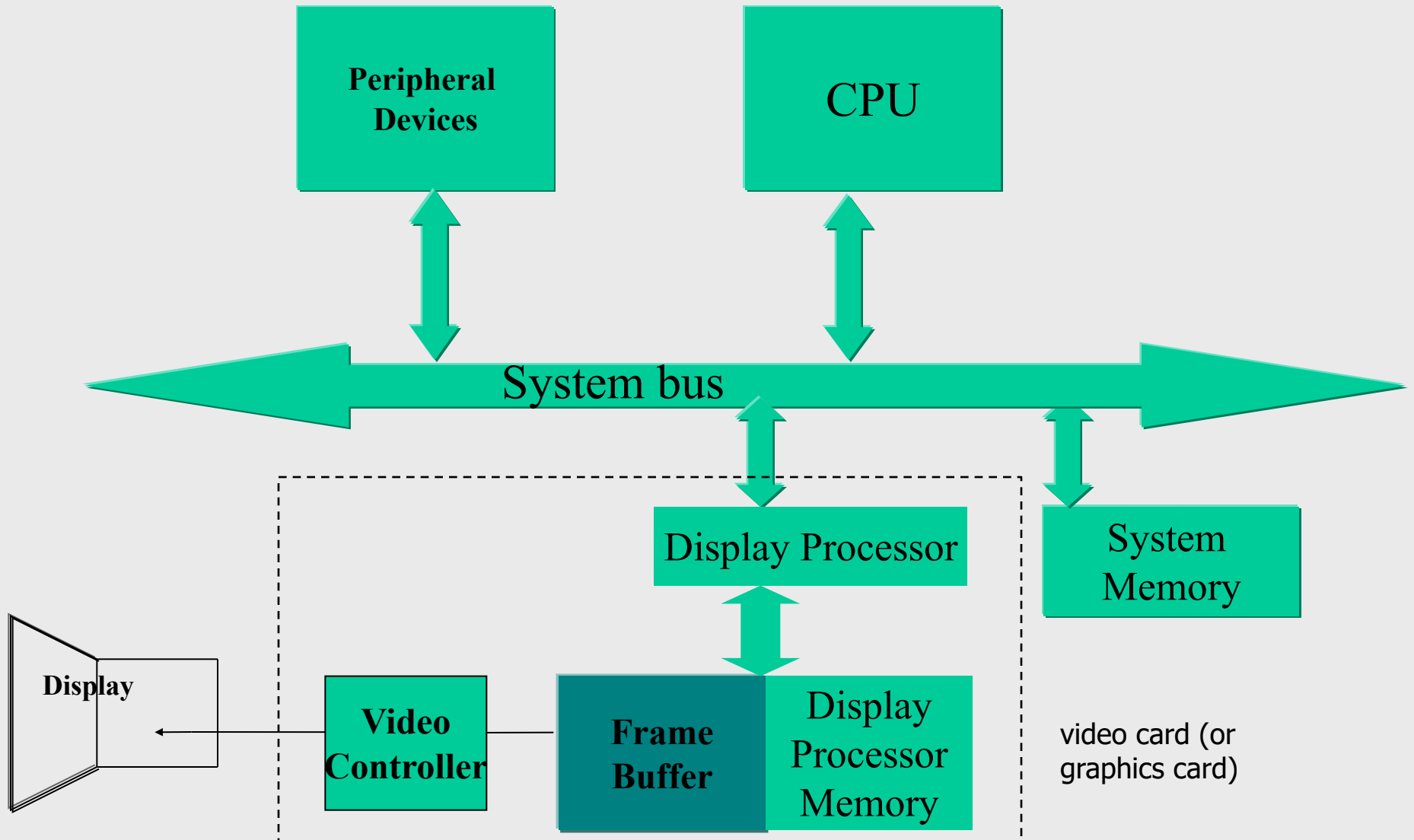
Raster display (since 1970s)

- Raster system consists of:
 - display processor (performs rendering)
 - video controller (accesses frame buffer to refresh monitor)
 - frame buffer (memory where image is created)
 - CRT (or other types of displays)

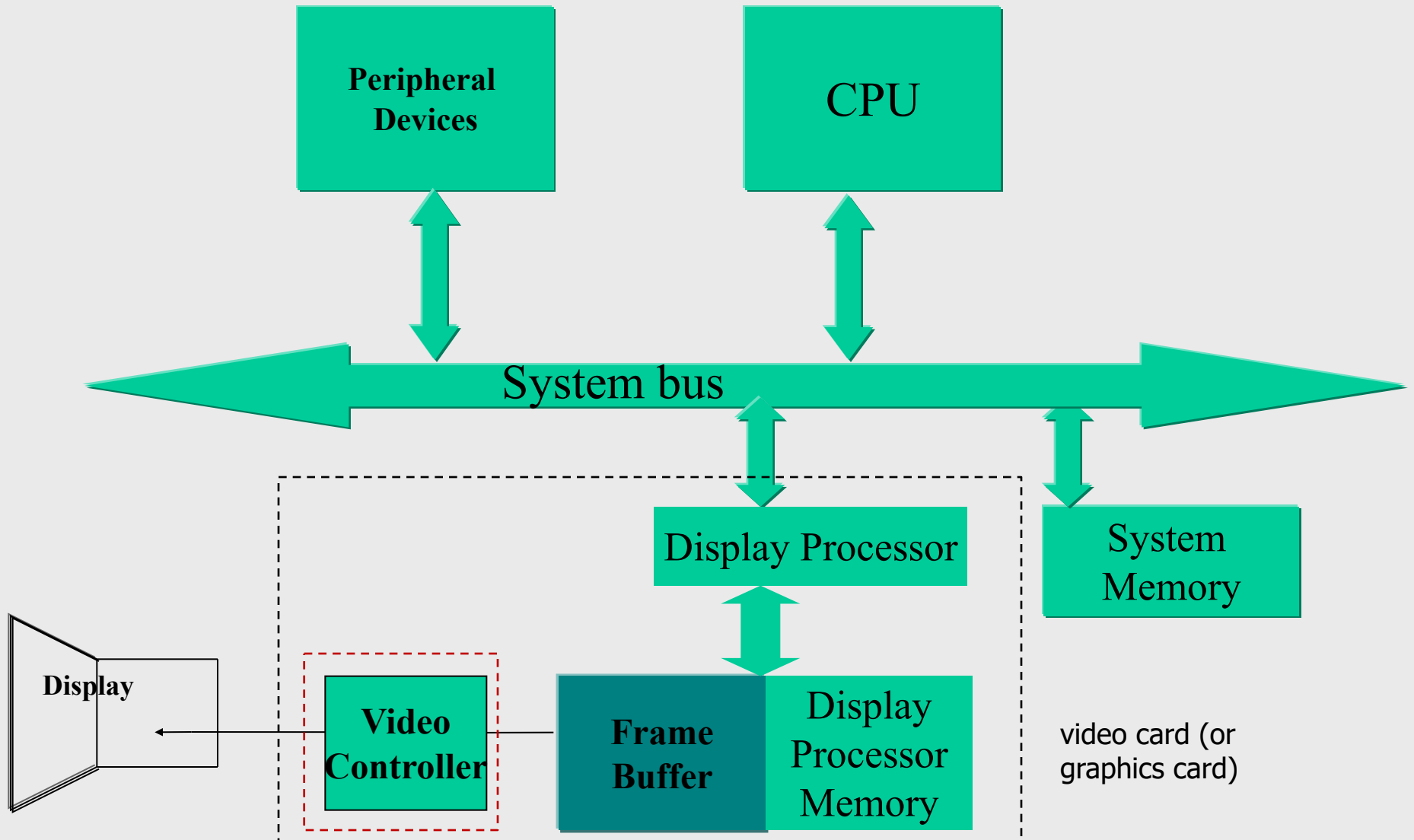


- The frame buffer stores primitive *pixels*, rather than display list or display program
- Video controller reads frame buffer to produce the actual image on the monitor
- The image is represented as a matrix of pixels.
- Need to refresh the raster display (e.g., 60Hz)

Common Raster Display System



Common Raster Display System



Video Controller

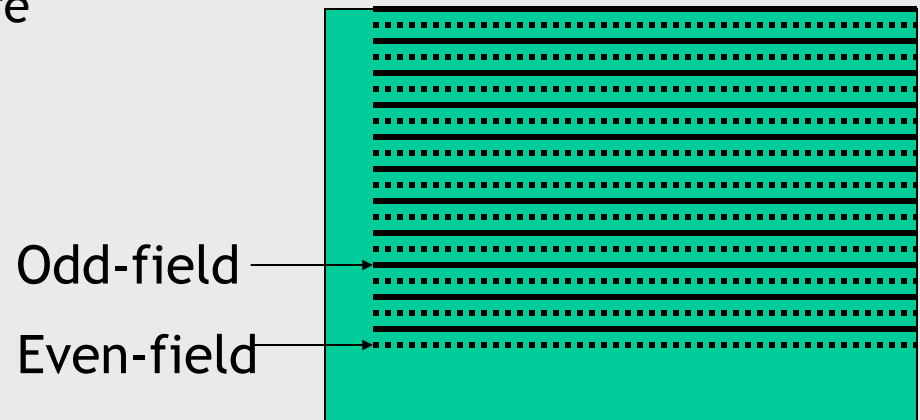
- Accesses the frame buffer to refresh the screen
- Controls the operation for display
- Types of refresh:

Interlaced (was developed for TV to reduce flickering effect on older CRT displays with lower refresh rate)

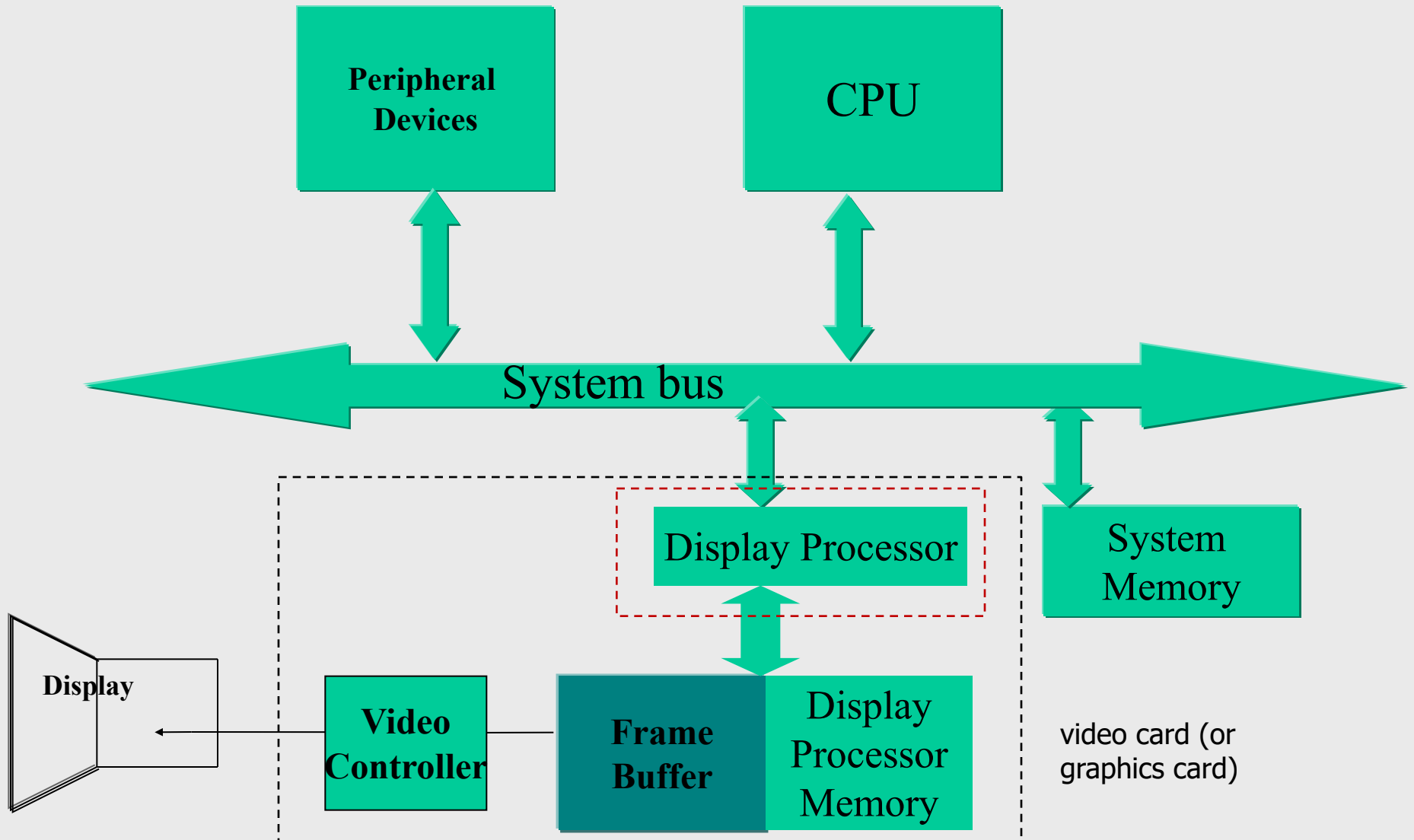
- two fields for one frame
- odd-field: odd-numbered scan lines
- even-field: even-numbered scan lines
- refresh rate: e.g., 60Hz (60 fields per sec, 30 frames/s)
- still in use as a video format (e.g., 720p vs 1080i)

Non-interlaced (progressive scan, mostly for monitors)

- refresh rate: e.g., 60Hz or more



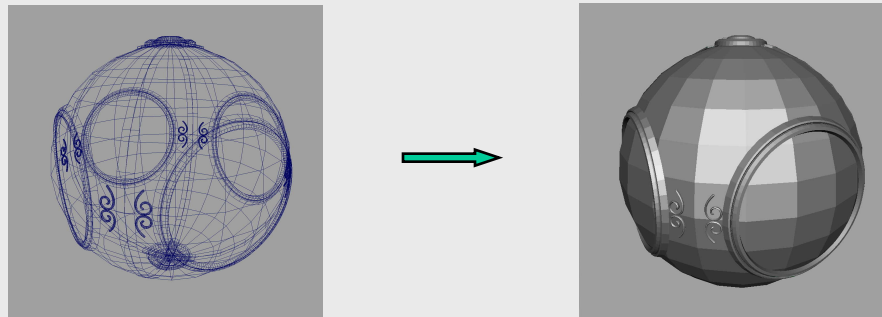
Common Raster Display System



Display Processor

Also called a **Graphics Processing Unit (GPU)**

- Specialized hardware to assist in rendering graphical (2D or 3D) primitives into the frame buffer:



- Fundamental difference among graphics systems is how much of graphics work the display processor does versus how much is done by the general-purpose CPU.
- Shaders