Graphics System

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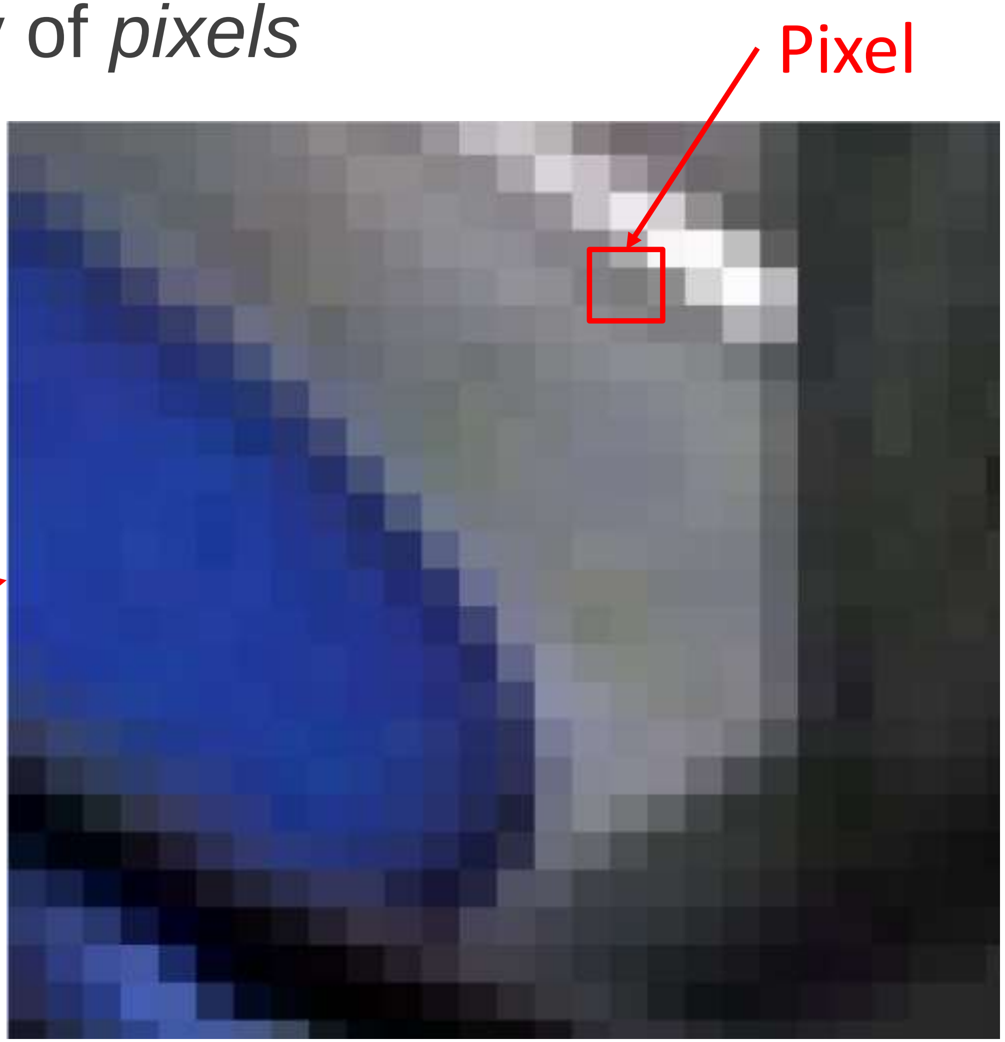
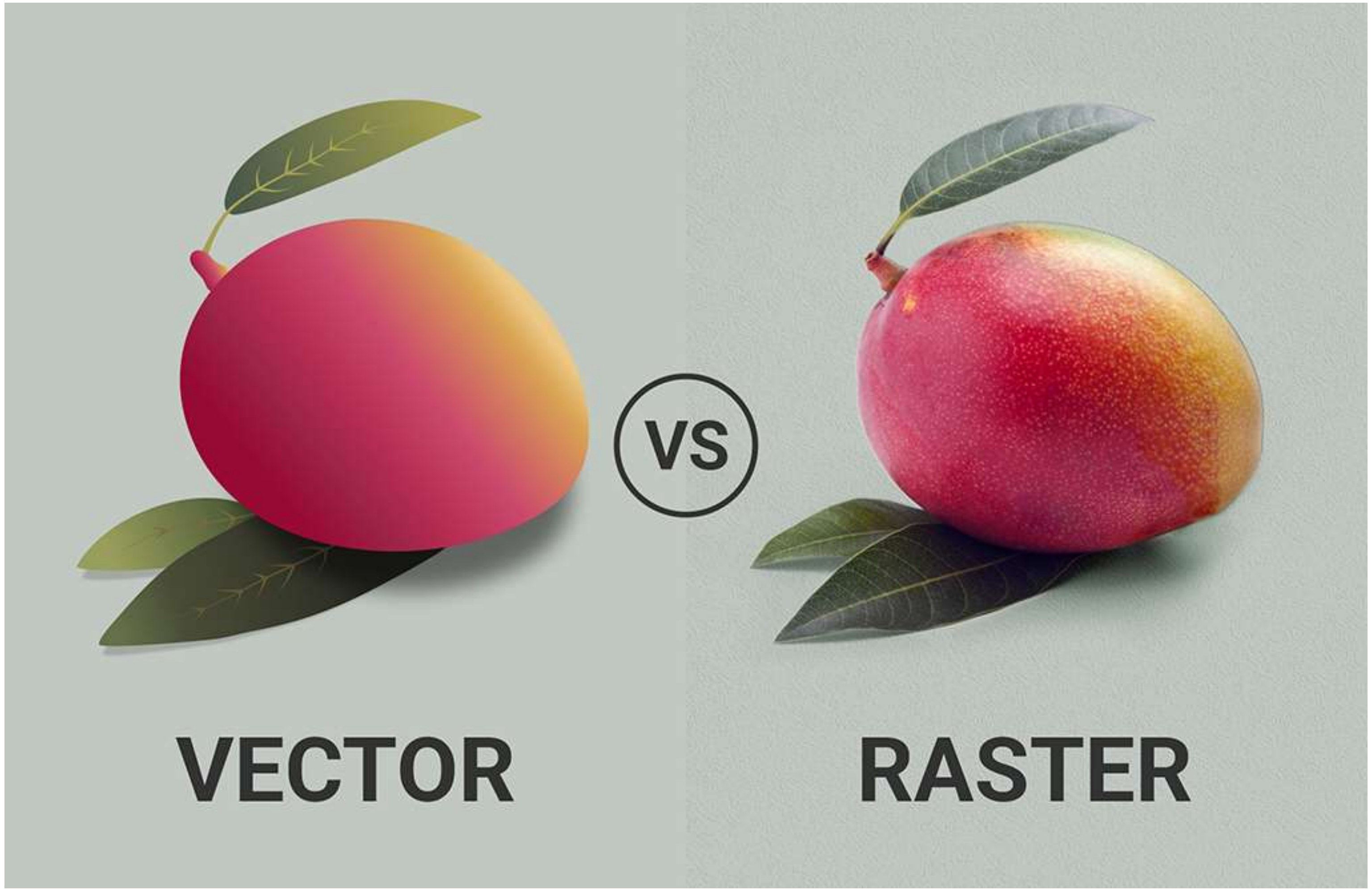
Raster Image

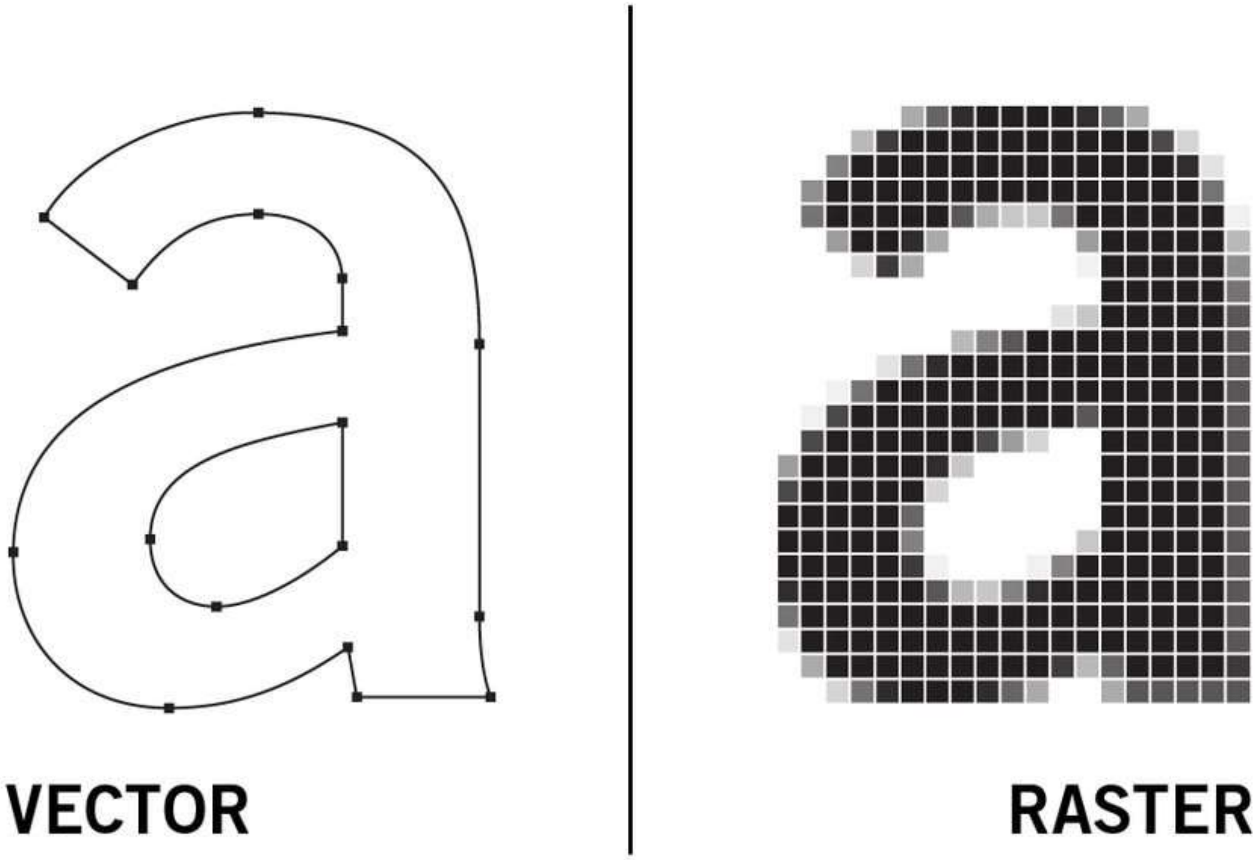
Raster Image: a rectangular array of *pixels*



Vector Image vs. Raster Image

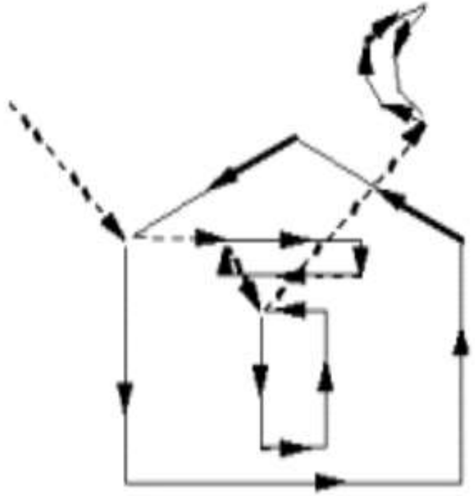


Vector Image vs. Raster Image

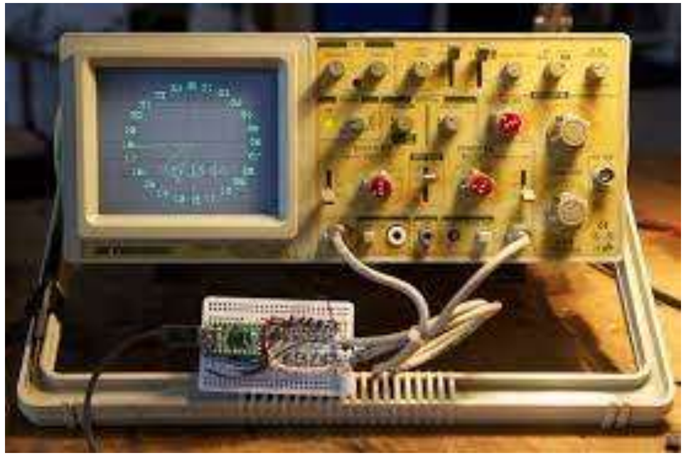


Vector Graphics Drawing

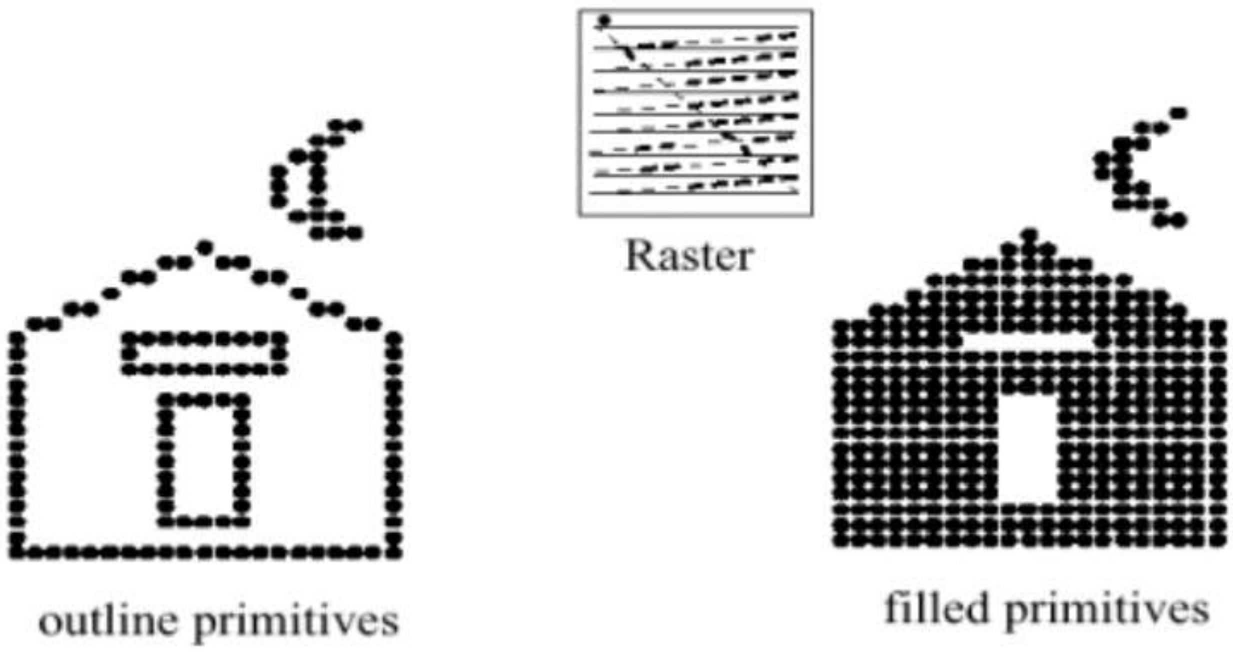
Ideal Drawing



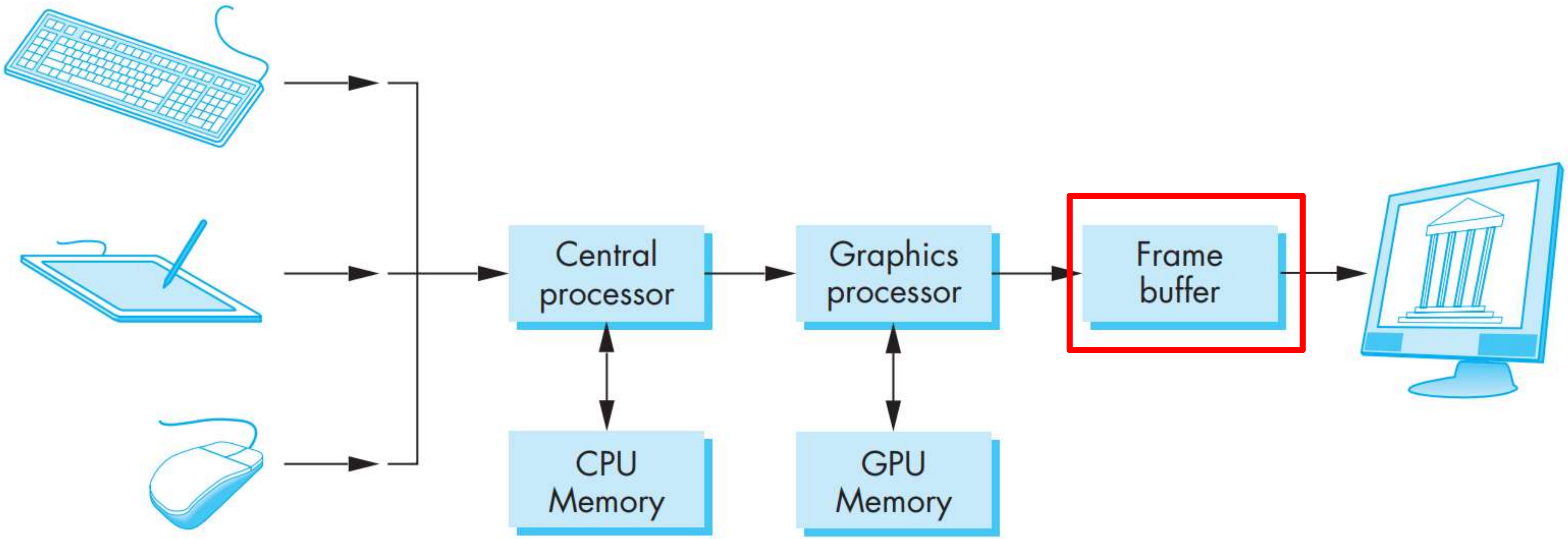
Vector Drawing



Raster Graphics Drawing



Graphic System



(Modern) Graphic System

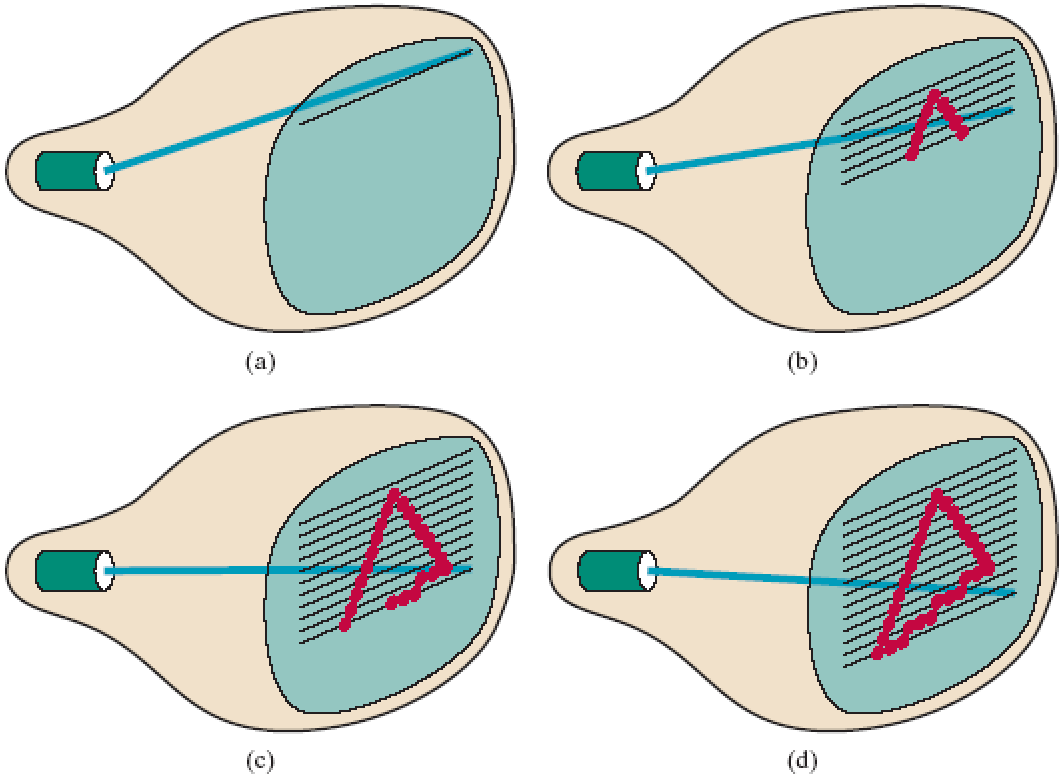
Raster Devices

- Output
  - Display
    - Transmissive: Liquid Crystal Display (LCD)
    - Emissive: Light-Emitting diode Display(LED)
  - Hardcopy
    - Binary: ink-jet printer
    - Continuous tone: dye sublimation printer

  - Input
    - 2D array sensor: digital camera
    - 1D array sensor: flatbed scanner

Display Devices

- Raster-scan display

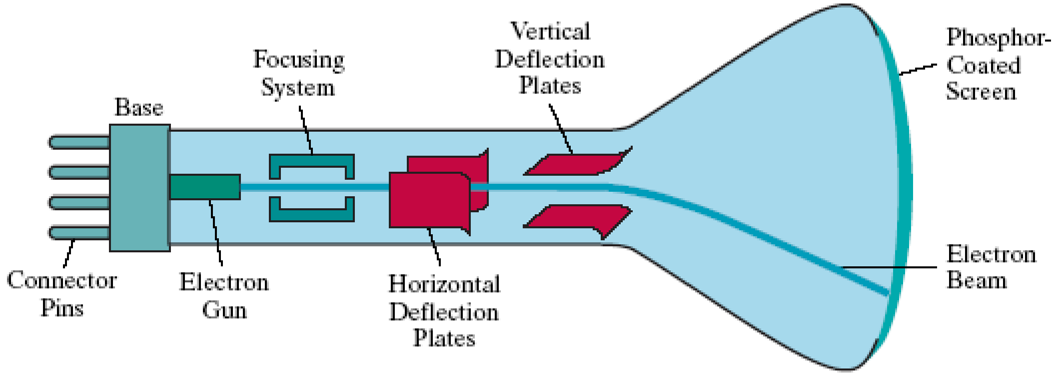


A raster-scan system displays an object as a set of discrete points across each scan line.

Display Devices

- CRT (Cathode-Ray Tube) Display
  - Electron gun emits electrons (a beam) from cathode
  - Anode draws/accelerates electrons
  - Electrons pass through focusing and deflection systems
  - Electrons hit phosphor-coated screen
  - The light emitted by the phosphor

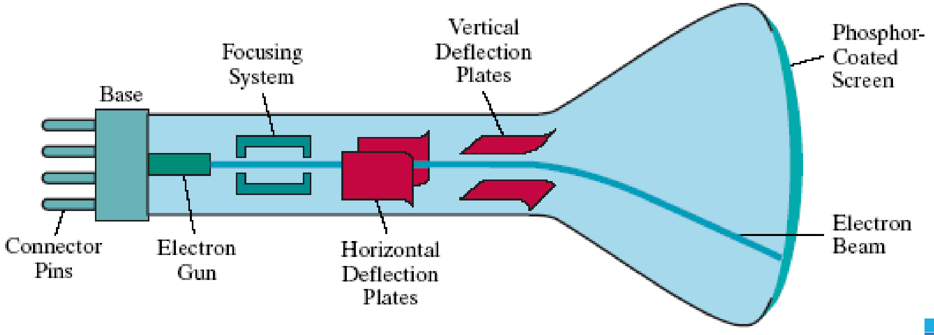
Electrostatic deflection of the electron beam in a CRT.



Display Devices

- CRT
  - Vector CRT (random-scan):
    - the voltages steering the beam change at a constant rate
    - Used in early graphics system
  - Refresh CRT
    - The phosphor emits light for a short time after the phosphor is excited by the electron beam

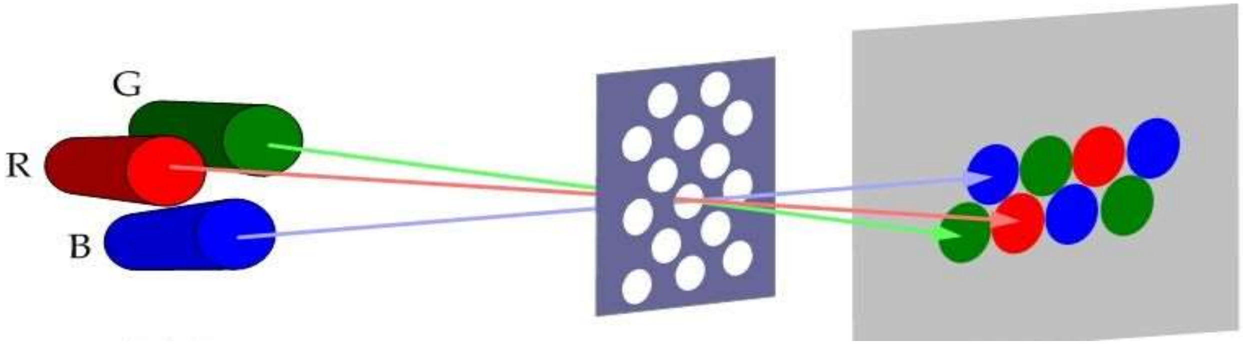
  ⇒ The same path must be retraced by refreshing CRT (ex. 60Hz)
  - Noninterlaced vs. interlaced display

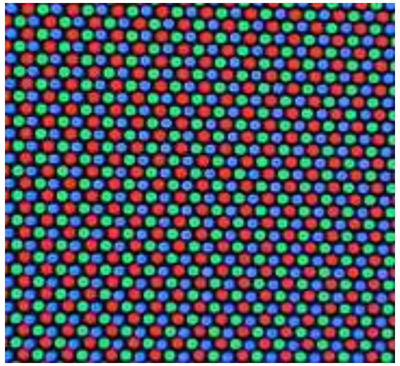


Electrostatic deflection of the electron beam in a CRT.

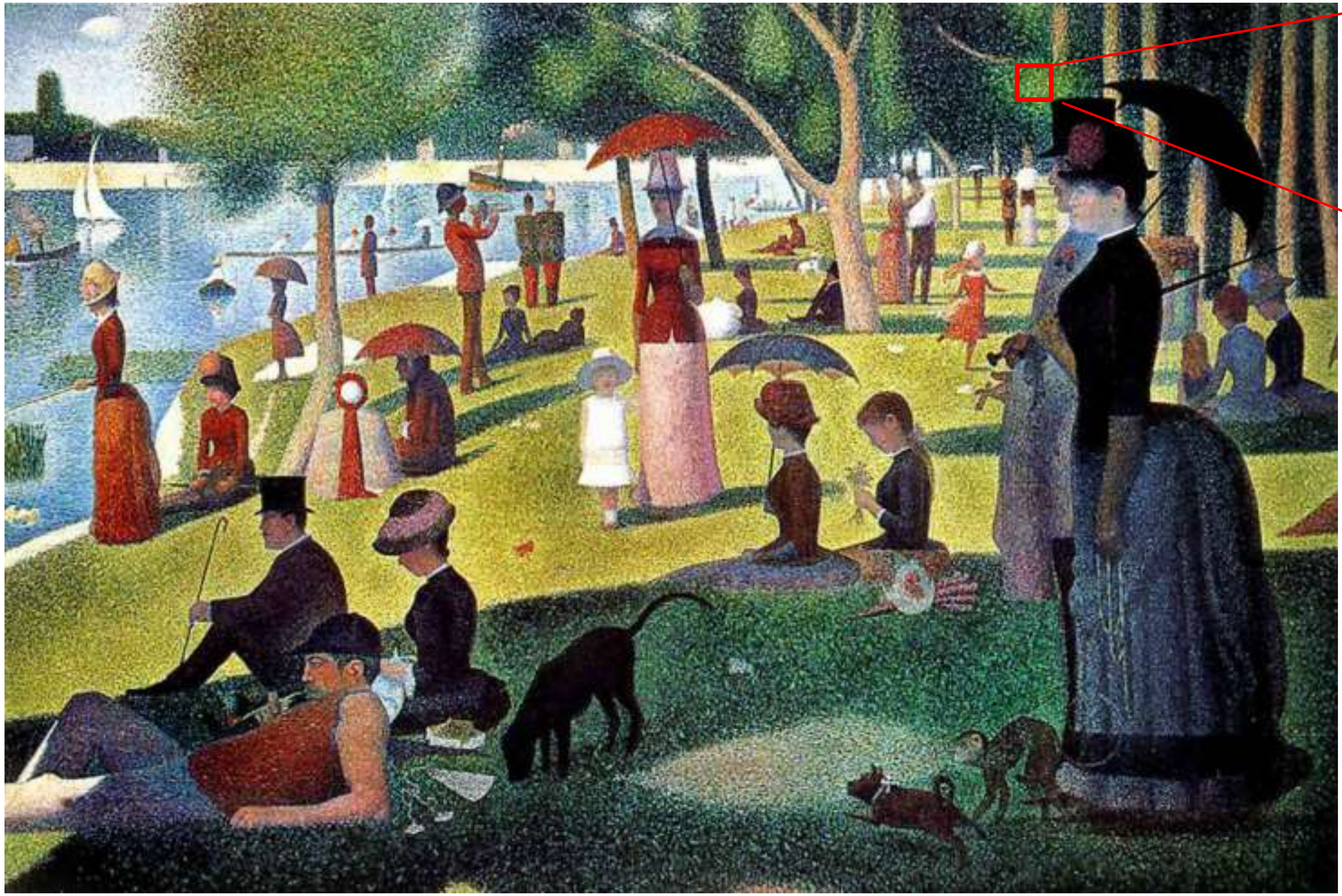
Display Devices

- Color CRT
  - Three different colored phosphors (red, green, blue) arranged in small groups
  - Shadow-mask CRT: an electron beam excites only phosphors of the proper color by using shadow-mask (a metal plate with small holes)
  - Colors are obtained by varying the intensity of three beams





Display Devices

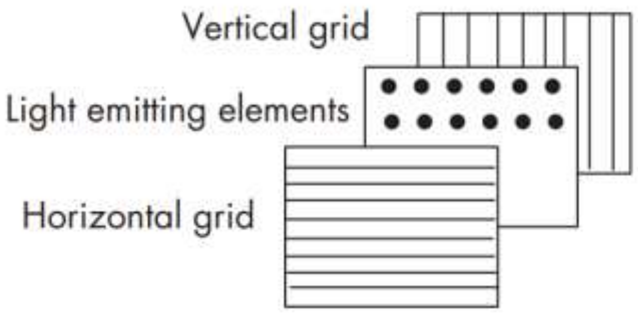


신인상주의 점묘법: 조르주 쇠라, 그랑드 자트 섬의 일요일 오후 (1886)

Display Devices

- Flat-panel display devices: raster based
  - Use a two-dimensional grid to address individual light-emitting elements
  - Emissive displays: pixels directly emit controllable amount of lights
  - Transmissive displays: pixels don't emit light, but vary the amount of light to pass through them

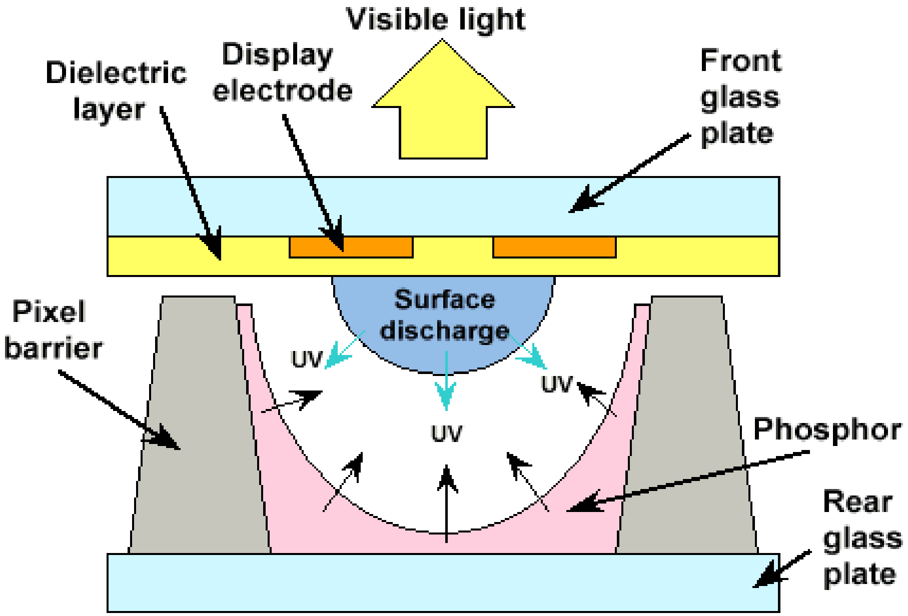
    $\Rightarrow$ Require a light source to illuminate pixels (Backlight in LCD, light lamp in projector)
  - Flat-panel display has a fixed *resolution* determined by the size of the grid (e.g. 1920 x 1200 pixels)



Generic flat-panel display.

Flat-panel Display Devices

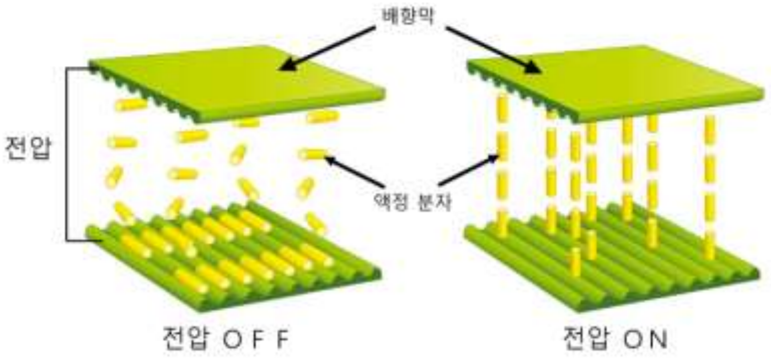
- Plasma Display Panel (PDP)
  - Voltages on the grid energize gases embedded between the glass panels

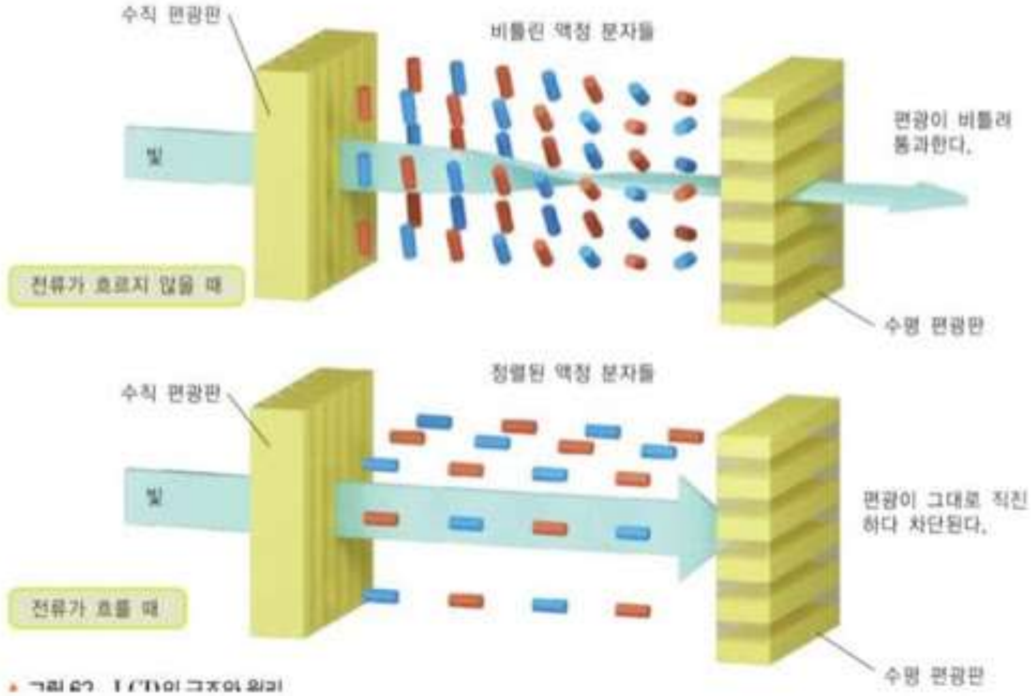


Plasma pixel

Flat-panel Display Devices

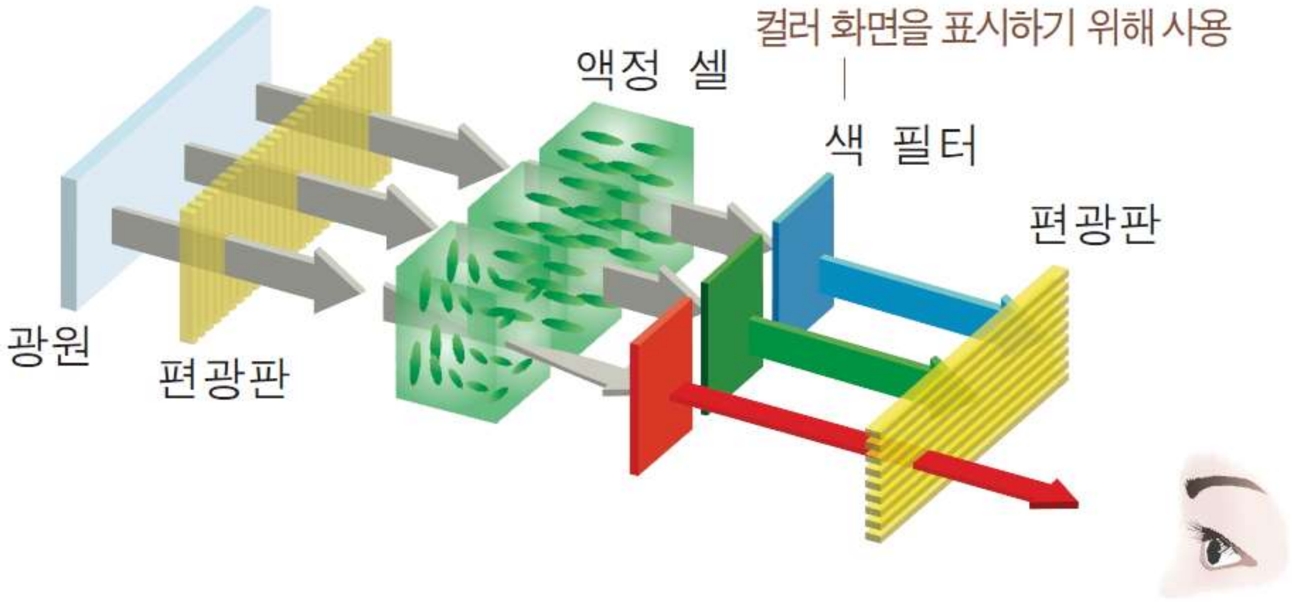
- Liquid Crystal Display (LCD)





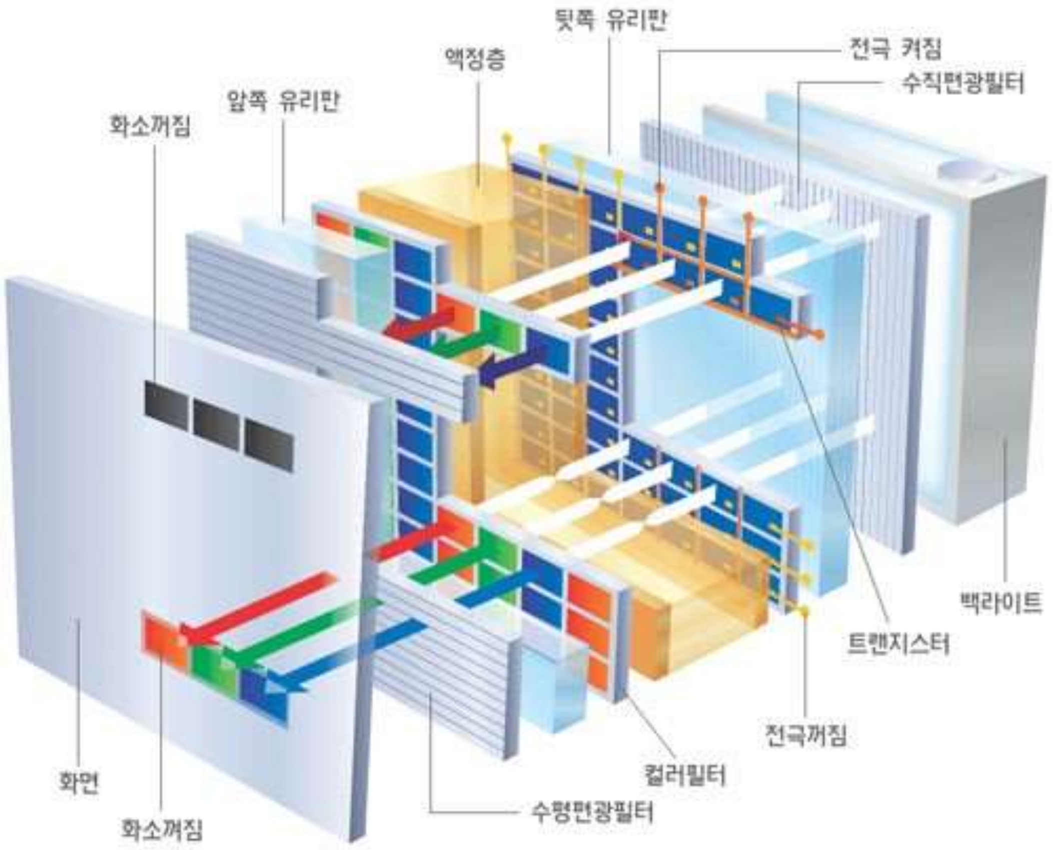
Flat-panel Display Devices

- LCD



Flat-panel Display Devices

- LCD



Flat-panel Display Devices

- Light-Emitting diode Display (LED)
  - Each pixel is composed of LED(s), semiconductor device(s) (based on inorganic or organic semiconductors), emitting light with intensity

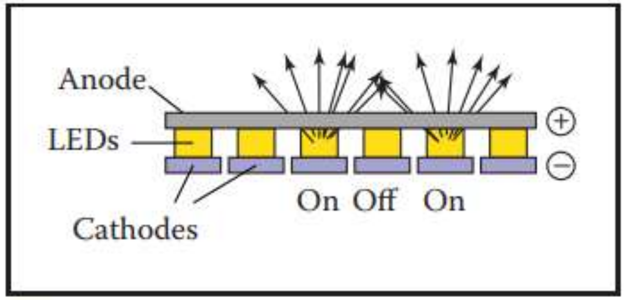


Figure 3.1. The operation of a light-emitting diode (LED) display.

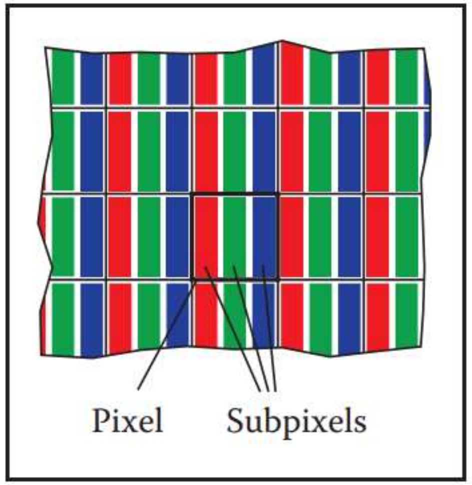
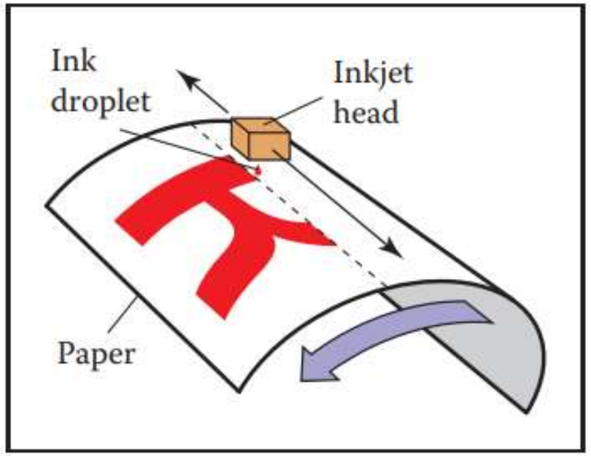


Figure 3.2. The red, green, and blue subpixels within a pixel of a flat-panel display.

Hardcopy Devices

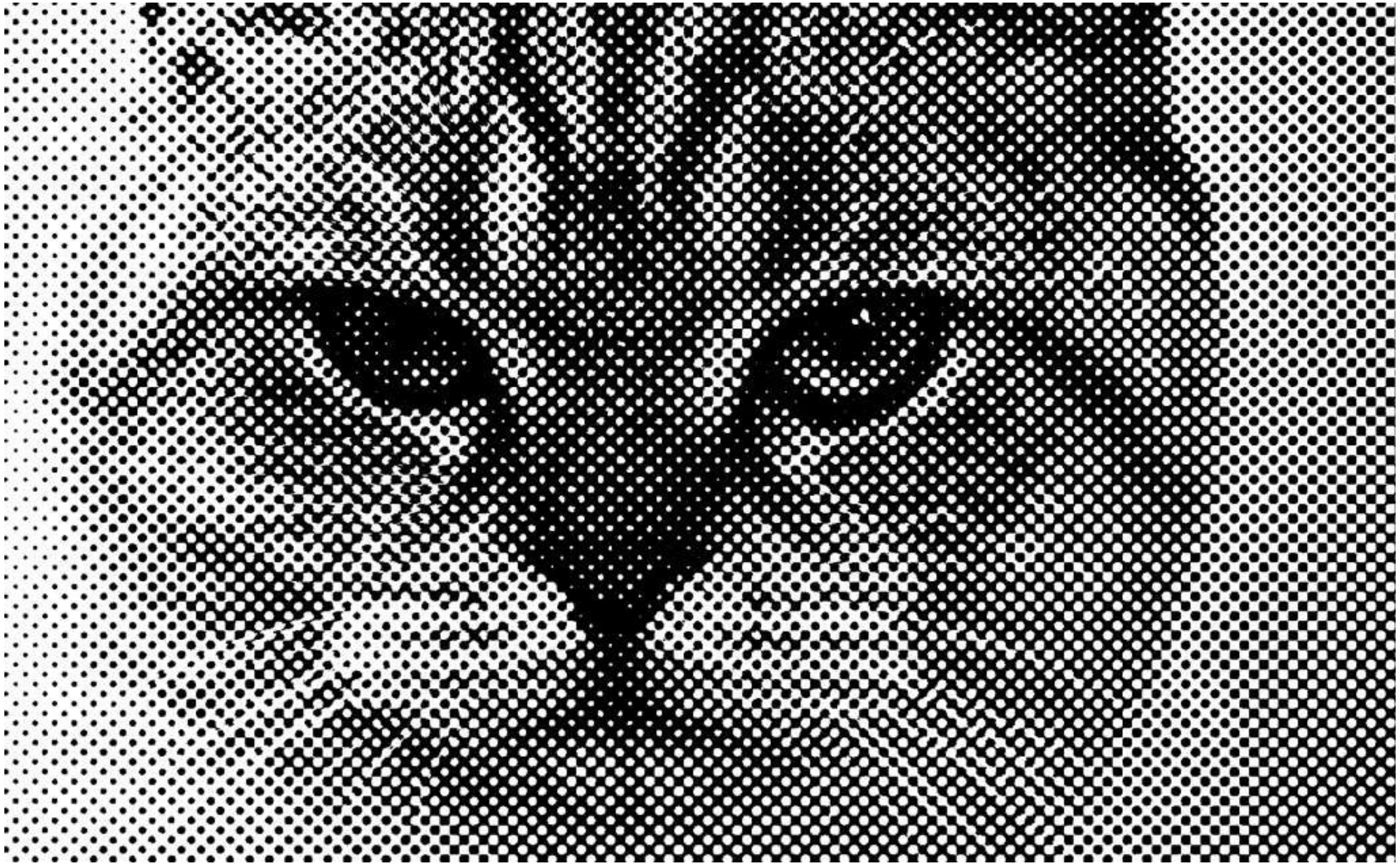
- Hardcopy devices (printers)
  - Binary images: pigment is either deposited or not (cannot be refreshed)
  - Ink-jet printer
    - Printer head sprays a small drop of liquid ink under electronic control
    - Color prints are made by using different print heads
    - No physical array of pixels
    - Resolution of printers: ppi (pixels per inch), dpi (dots per inch)
    - Stairstepping (aliasing) appears near edges

    $\Rightarrow$ Very high resolution or *halftoning*



The operation of an ink-jet printer.

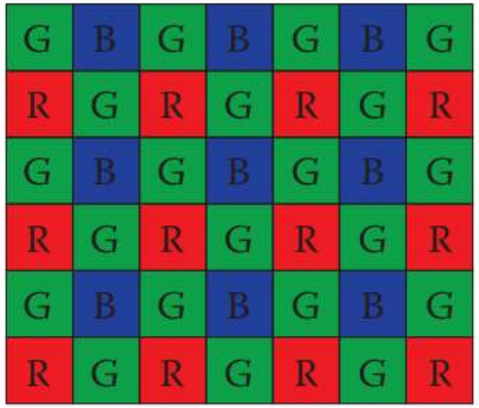
Hardcopy Devices



Halftoning

Input Raster Devices

- A Digital Camera
  - 2D array input device: the image sensor is a semiconductor device with a grid-of light-sensitive pixels
  - Camera lens projects an image of the scene to the sensor
  - Pixels the sensor measure the light energy falling on them
  - Demosaicking: software fills the missing image values
  - Resolution is determined by the number of pixels



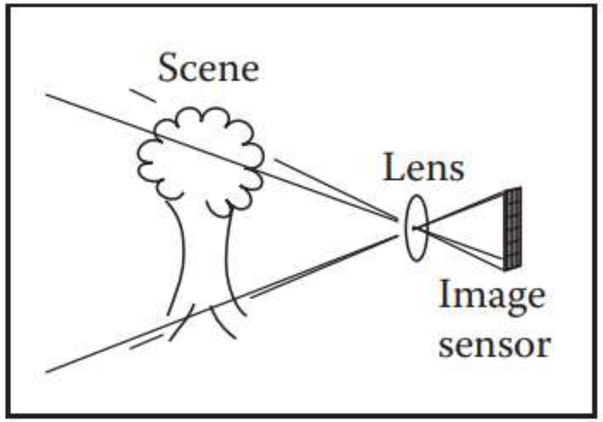
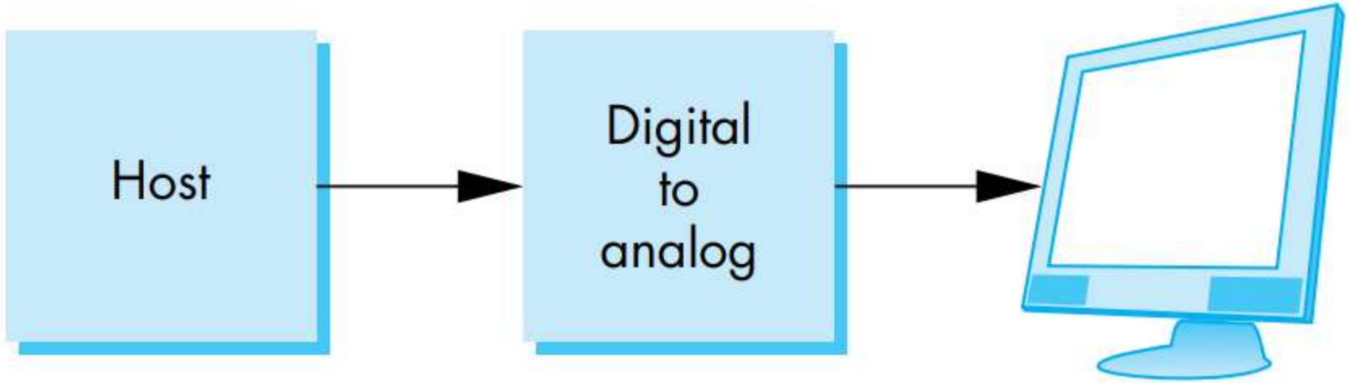


Figure 3.8. Most color digital cameras use a color-filter array similar to the *Bayer mosaic* shown here. Each pixel measures either red, green, or blue light.

Graphics Architecture

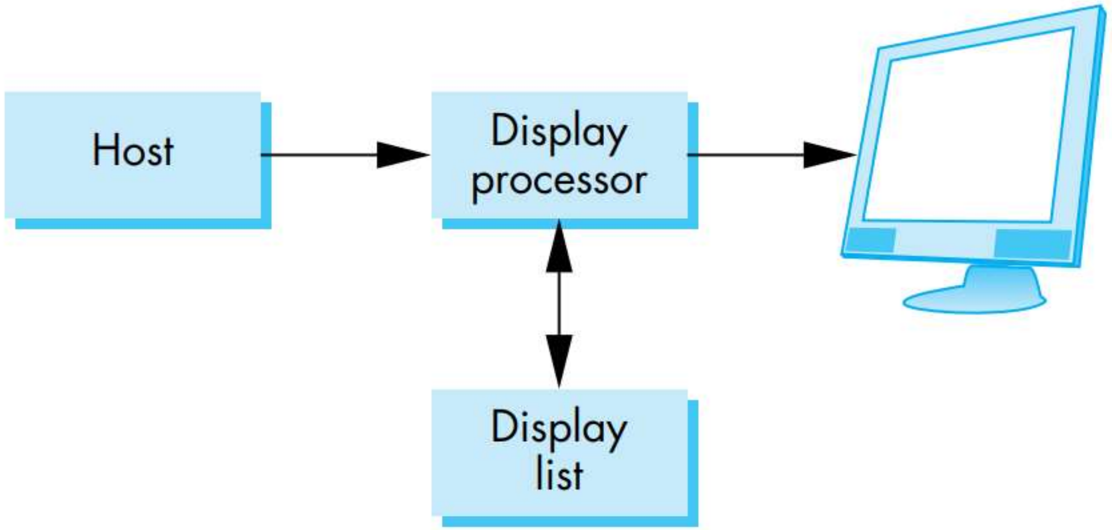
- Early graphics system (based on vector graphics)
  - Used general-purpose computers for drawing
  - Host computer:
    - Run applications to compute end points of line segments
    - Information has been sent to CRT display



Early graphics system.

Graphics Architecture

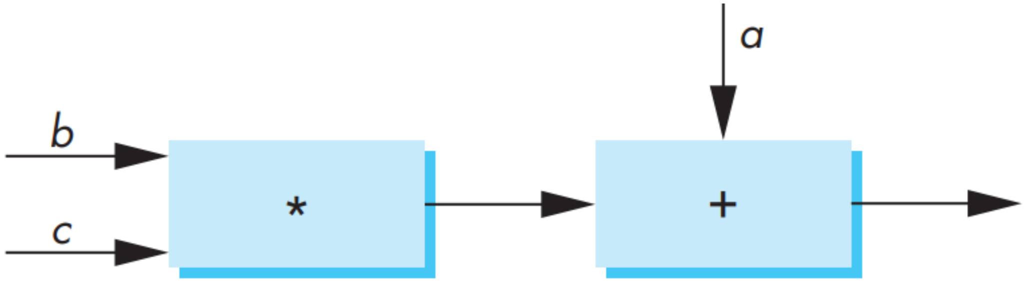
- Display processors
  - Information has been stored in the display processors' own memory



Display-processor architecture.

Graphics Architecture

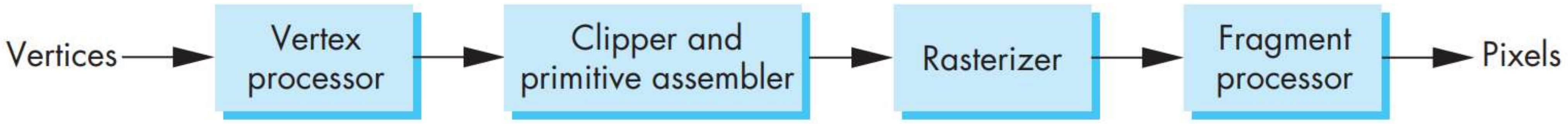
- Pipeline Architecture
  - Developed with the advances in special-purpose VLSI chips and decreased cost of solid-state memories
  - The system is evaluated with the throughput and the latency
  - Good when performing many repetitive computations



Arithmetic computation ((b * c) + a)

Graphics Architecture

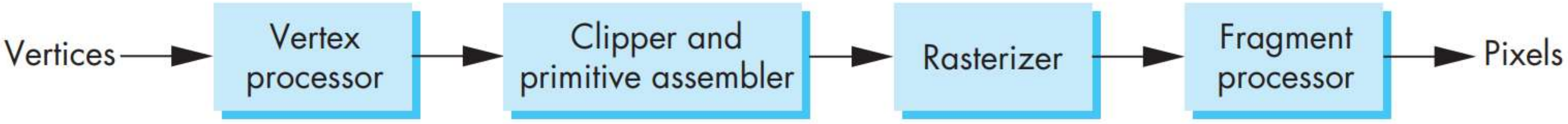
- Graphics Pipeline
  - Process a set of objects (vertices) to pixels in frame buffer



Geometric pipeline.

Graphics Pipeline

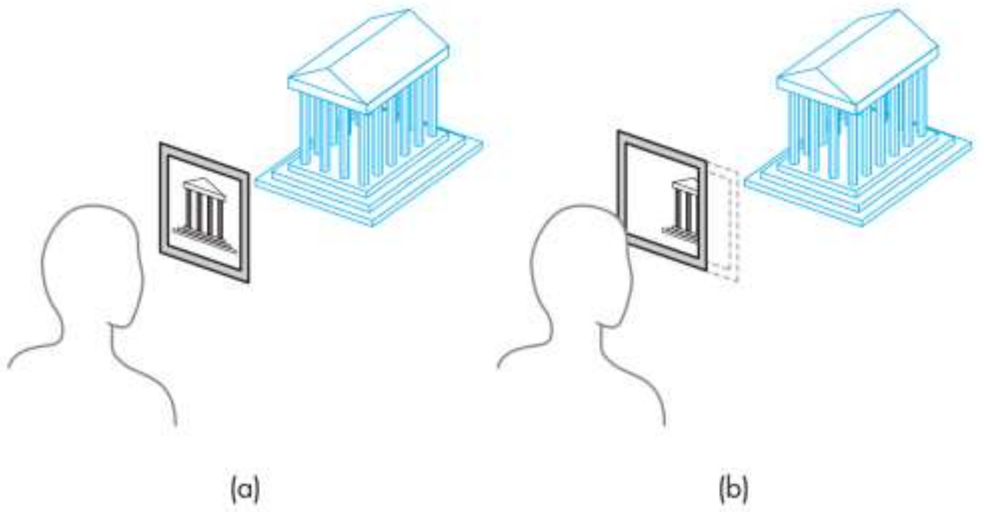
- Vertex processing
  - Process each vertex (of geometric objects) independently
  - Tasks: coordinate transformations (matrix concatenations), color computation of each vertex



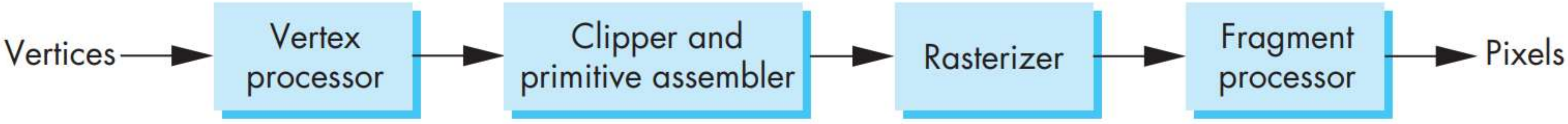
Geometric pipeline.

Graphics Pipeline

- Clipping and Primitive Assembly
  - Clip parts of scene that is out of camera view
  - Clipping must be done on a primitive-by-primitive basis
  - Output: a set of primitives with projections appeared in the image



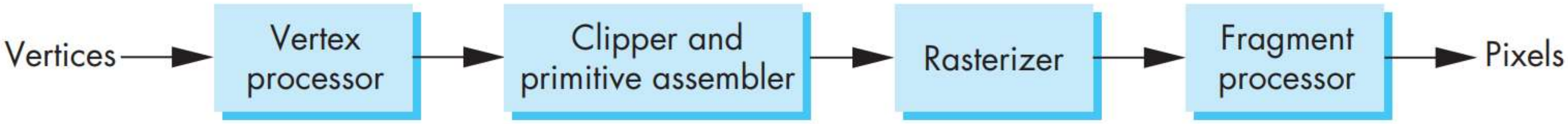
Clipping. (a) Window in initial position. (b) Window shifted.



Geometric pipeline.

Graphics Pipeline

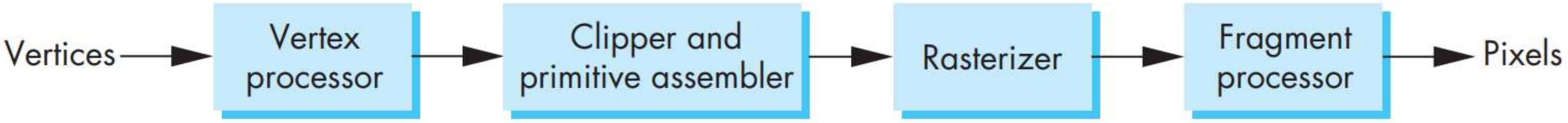
- Rasterization
  - Convert a set of primitives to pixels in frame buffer through rasterization (or scan-conversion)
  - Determines pixel information for each pixel (e.g. computing blended colors in polygons)
  - Output: a set of fragments for each primitive (pixel with color, location, depth, etc.)



Geometric pipeline.

Graphics Pipeline

- Fragment processing
  - Update pixels in the frame buffer from the fragments
  - Some fragments may not be visible if they come from the surfaces behind the scenes
  - Textures can be applied



Geometric pipeline.

Image

- What is image?
- We can abstract an image as a function:

$$I(x, y): R \rightarrow V,$$

where R is a rectangular area, V is the set of possible pixels

- Pixels in a raster image: point samples of an image

Image

- What is the location of a pixel?
  - Pixel coordinates: (0,0) (bottom left), $(n_x - 1, n_y - 1)$ (top right)
  - The domain of pixel (i, j): $[i - 0.5, i + 0.5] \times [j - 0.5, j + 0.5]$

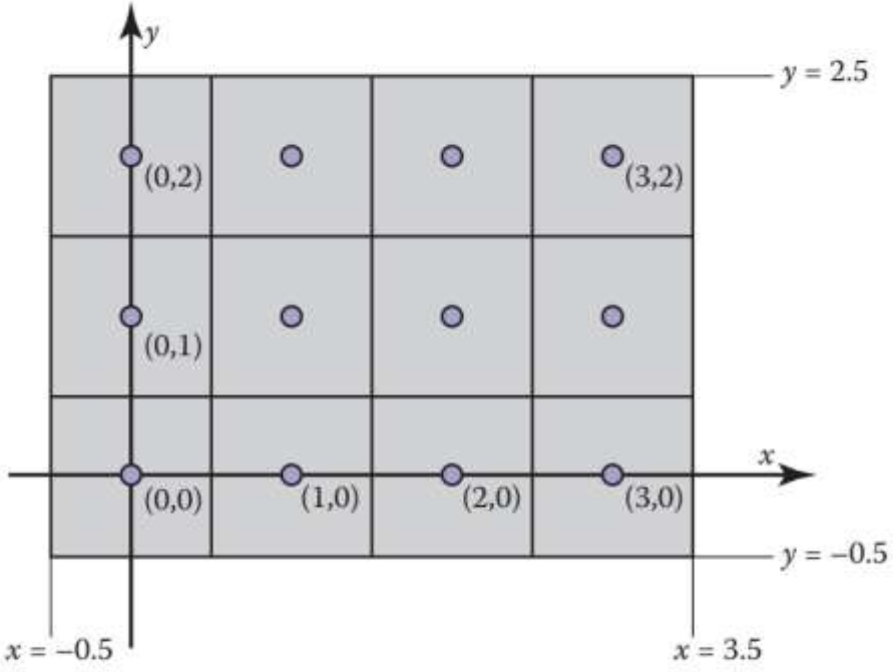


Figure 3.10. Coordinates of a four pixel × three pixel screen. Note that in some APIs the *y*-axis will point downward.

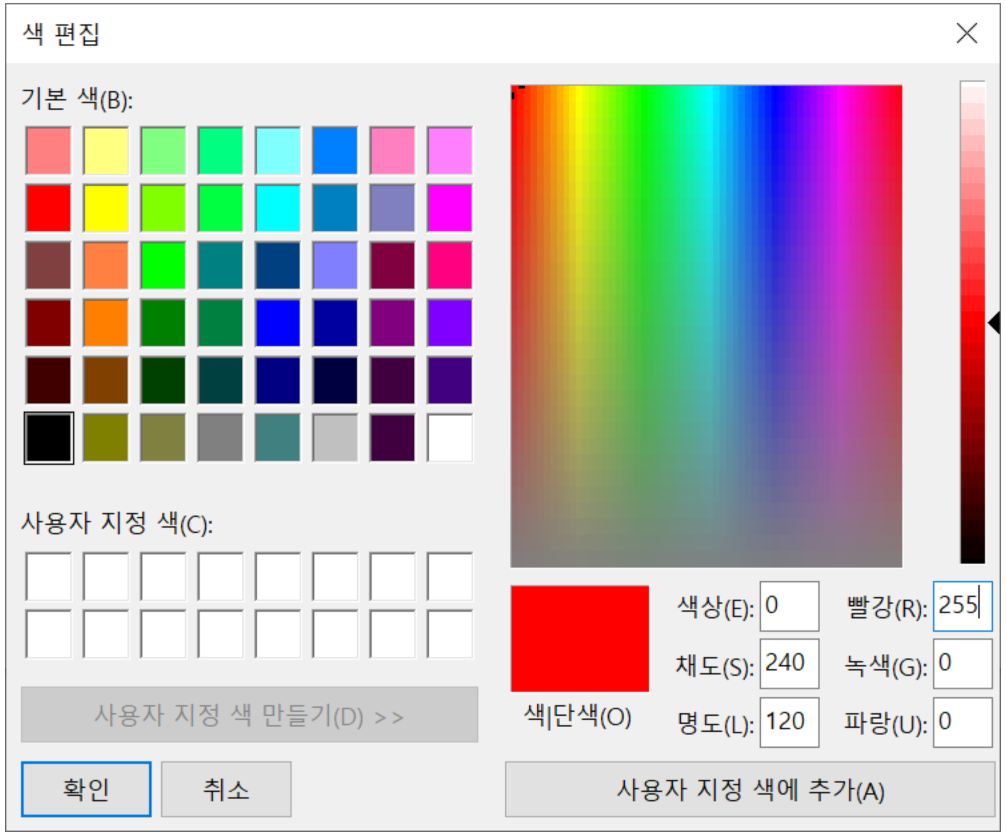
Pixel Values

- Pixel values
  - Real numbers representing the intensity of (red, green, blue) light at that pixel

  $\Rightarrow$ Images are arrays of (floating) number values
  - Intensity values are often bounded between minimum and maximum values (usually [0,1])

- Pixel formats
  - 1-bit (grayscale): binary color, 0 (black) and 1 (white)
  - 8-bit RGB fixed-range color (24 bits/pixel): web applications
  - 8- or 10-bit fixed-range RGB (24-30 bits/pixel)
  - 12- to 14-bit fixed-range RGB (36-42 bits/pixel): raw camera images
  - 16-bit fixed range RGB (48 bits/pixel): professional photography, printing
  - 16-bit “half-precision” floating-point RGB: HDR images (real-time rendering)
  - 32-bit floating-point RGB

Pixel Values



8-bit RGB fixed-range colors (each RGB color has the range of [0, 255])

Pixel Values

- High Dynamic Range (HDR) images

HDR (left) vs. SDR (right) images

Gamma

- We expect to map the range of pixel values linearly to the range of light intensity (e.g., 0 (black), 1 (white), 0.5 (half-gray))
- Monitors are nonlinear to input numbers

  (e.g. 0.5 outputs 0.025!)
- Monitors are characterized (approximately) by γ value:

$$displayed\ Intensity = (maximum\ intensity)a^{\gamma}$$

- Gamma correction

$$a' = a^{1/\gamma}$$

RGB Color

- RGB colors: apply additive mixing rules
- Some RGB color values
  - Black (0, 0, 0)
  - White (1, 1, 1)
  - Red (1, 0, 0)
  - Green (0, 1, 0)
  - Blue (0, 0, 1)
  - Yellow (1, 1, 0)
  - Cyan (0, 1, 1)
  - Magenta (1, 0, 1)…

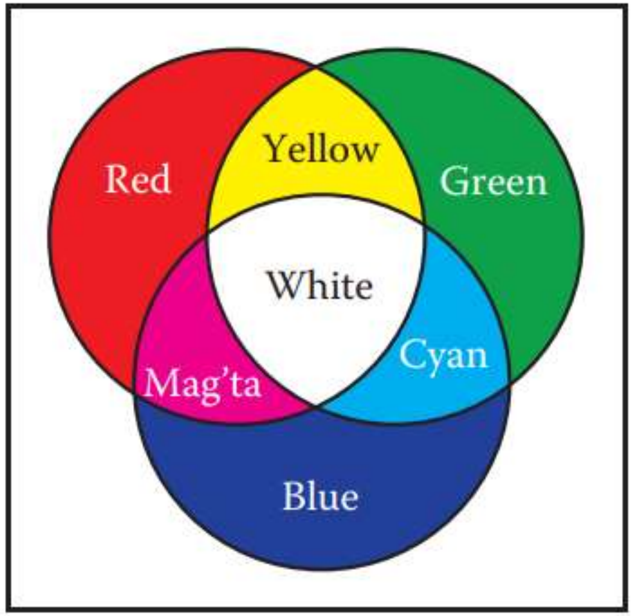
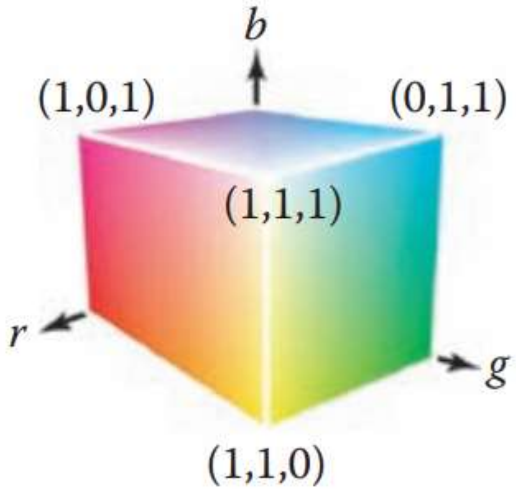
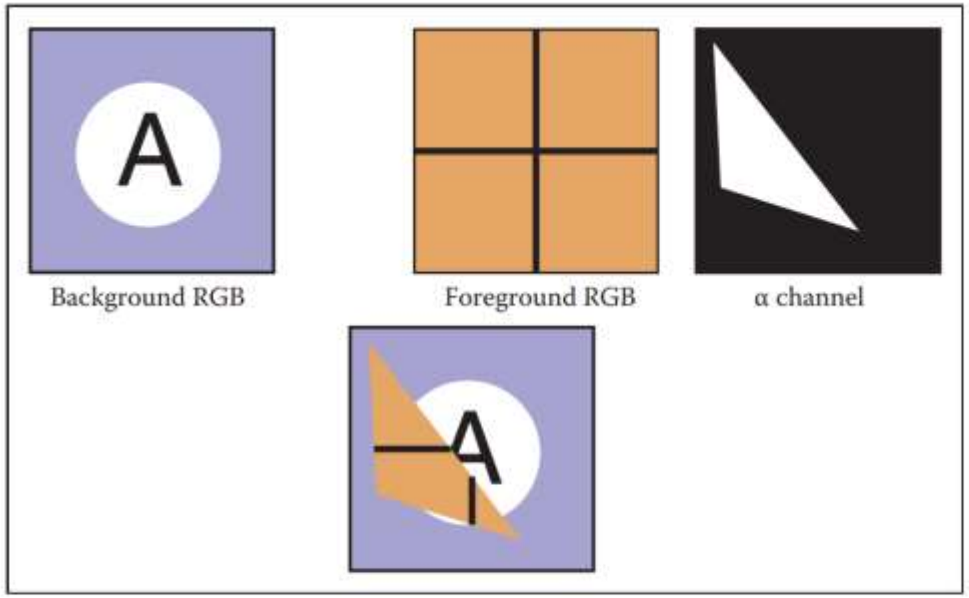


Figure 3.12. The additive mixing rules for colors red/-green/blue.



Alpha Compositing

- Add transparency information to pixels
- Useful for compositing foreground/background images
- α: the fraction of pixel covered by the foreground layer



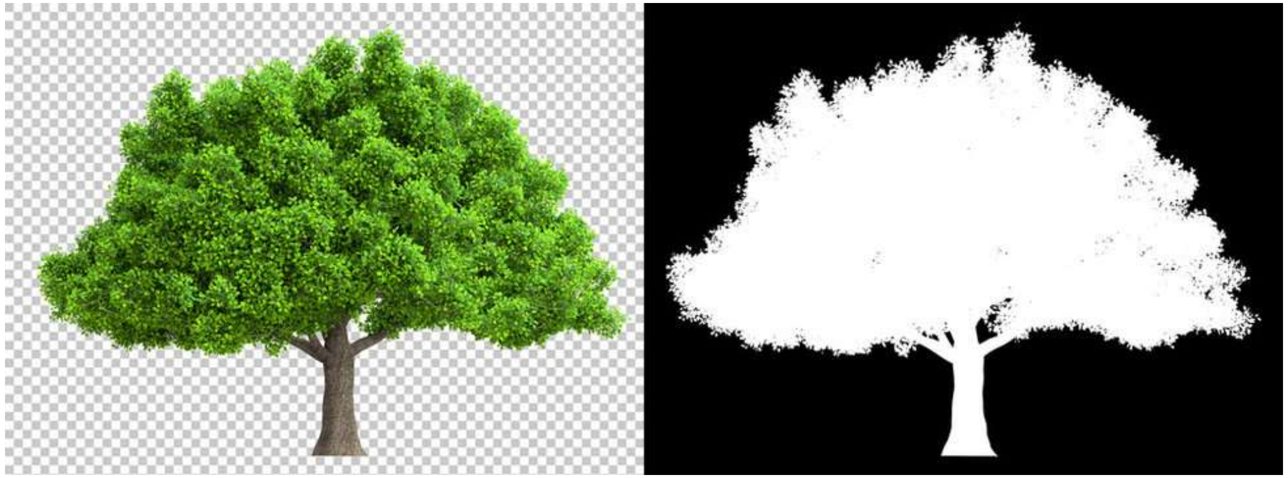
Alpha Compositing

- Color of a pixel

$$c = \alpha c_f + (1-\alpha)c_b,$$

where c_f, c_b are foreground and background color values

- Alpha values for the whole image is stored in alpha channel
- 32-bit pixel format is widely used to represent RGBA color



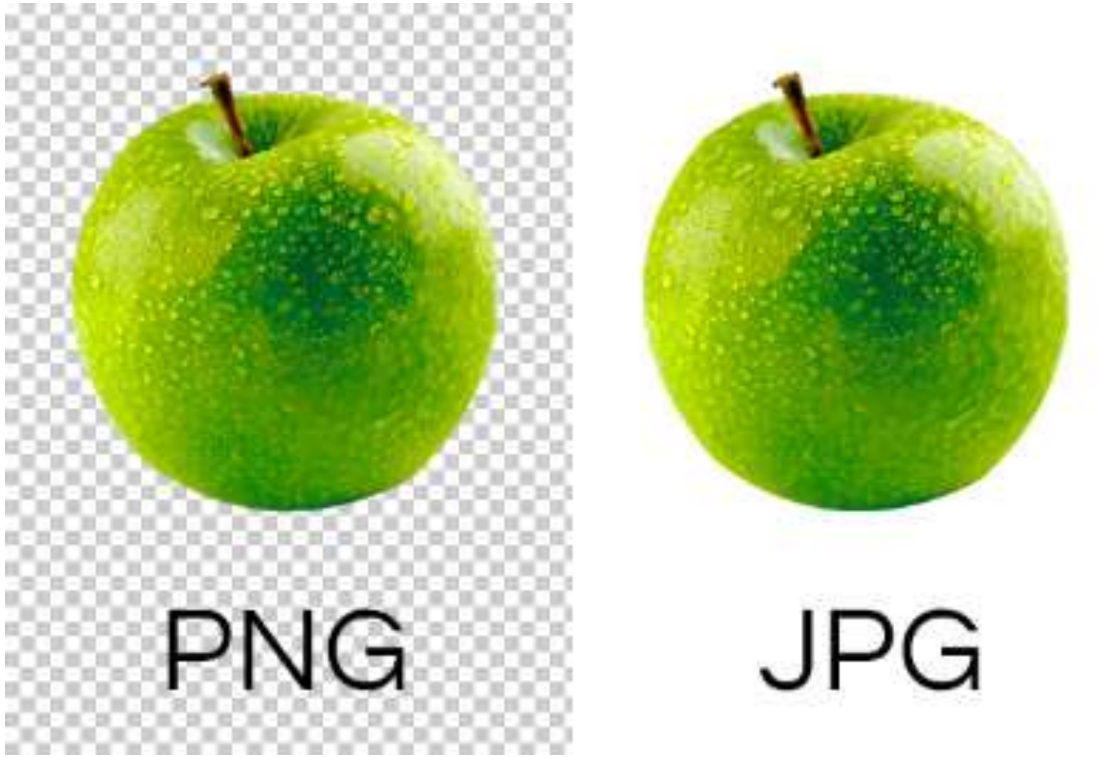
Alpha mask (stored in alpha channel)

Image Storage

- Most RGB image format use 8-bits for each of R,G,B channels
  $\Rightarrow$ Need 3 megabytes of raw information for a single million-pixel image
- Image file formats: need some level of compressions
  $\Rightarrow$ Lossless vs. Lossy
- Some image file formats
  - JPEG: lossy format, compress image blocks based on threshold
  - TIFF: widely used for binary images, losslessly compress 8/16-bit RGB
  - PPM: lossless, uncompressed format (8-bit RGB images)
  - PNG: lossless format, widely used

Image Storage

JPG vs. PNG



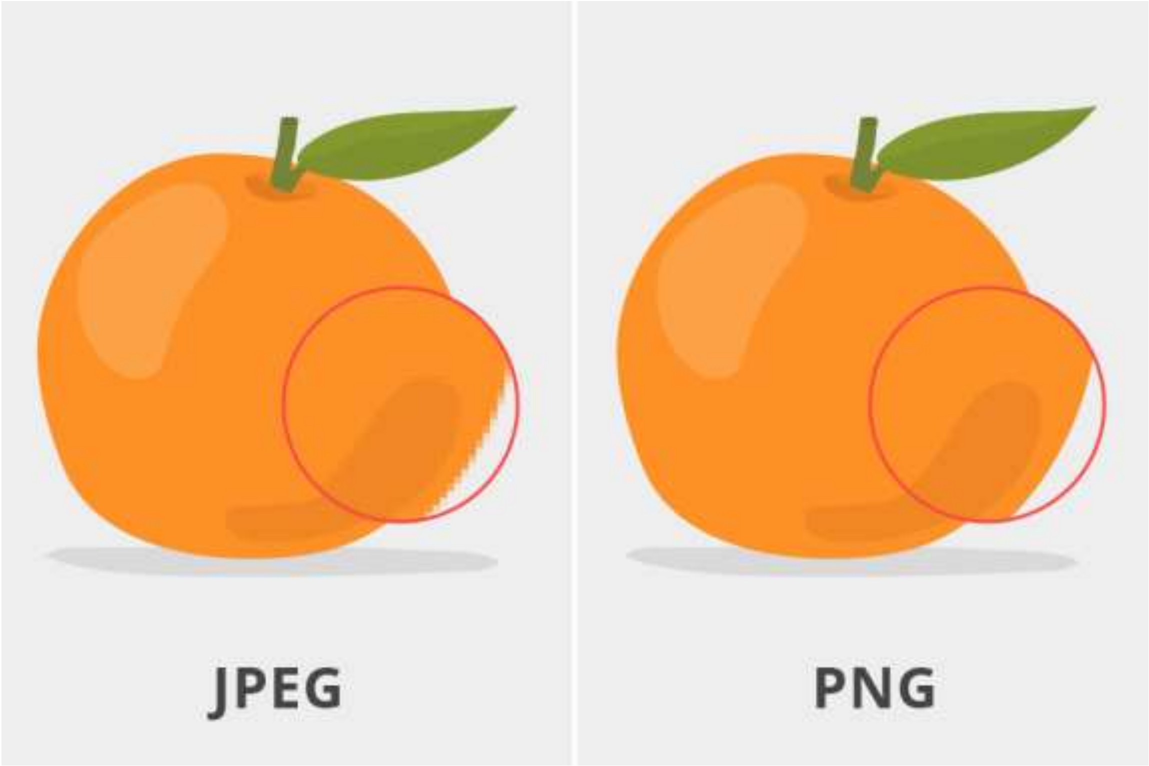


Image Storage

JPG vs. PNG

Summary

- Raster image
  - Raster image vs. vector image
- Graphic system
  - Raster image output and input devices
  - Graphics Pipeline
- Image (in abstract)
  - Pixel information (color, gamma, alpha)
  - Image storage formats