Graphics Systems and Models
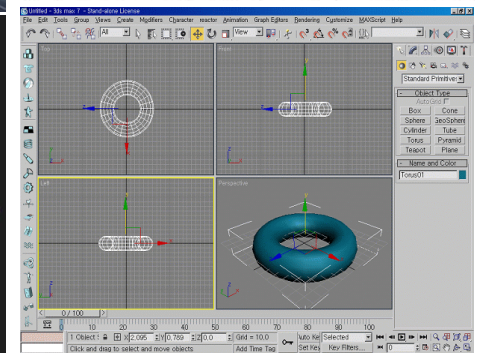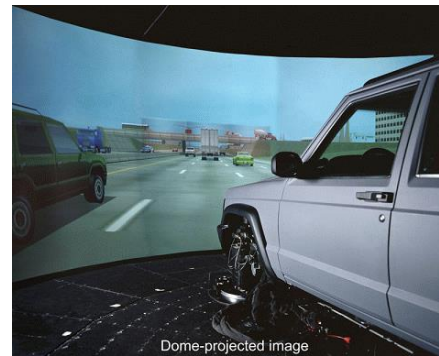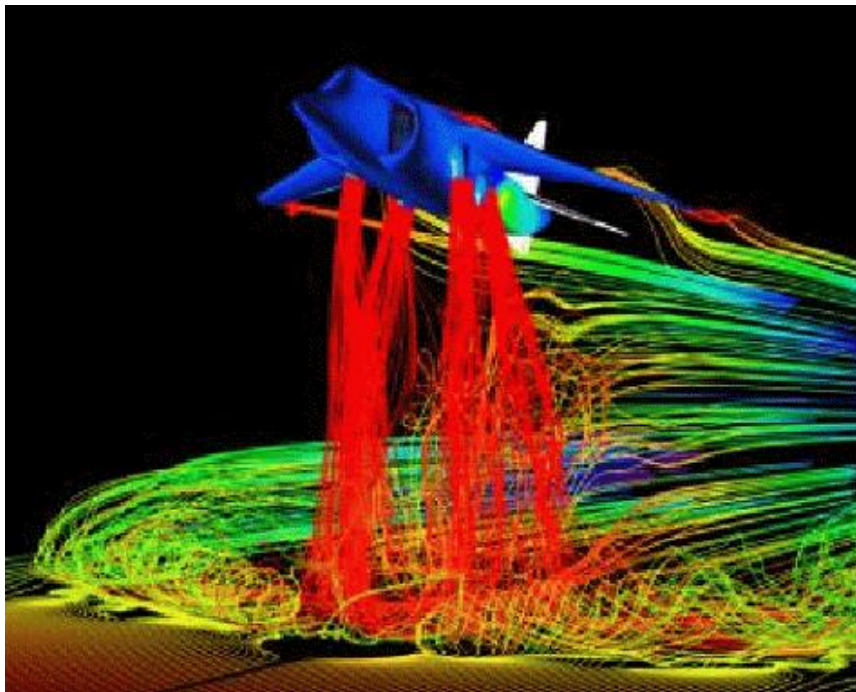
Fall 2023
9/14/2023
Kyoung Shin Park
Computer Engineering
Dankook University

Computer Graphics Applications

- Information Visualization
- Design
- Simulation, Animation
- User Interfaces

Computer Graphics Main Theme

- Imaging
  - Express 2D images effectively
- Modeling
  - Express 3D model objects effectively
- Rendering
  - Render into the 2D image from a 3D model
- Animation
  - Express the natural movement of objects
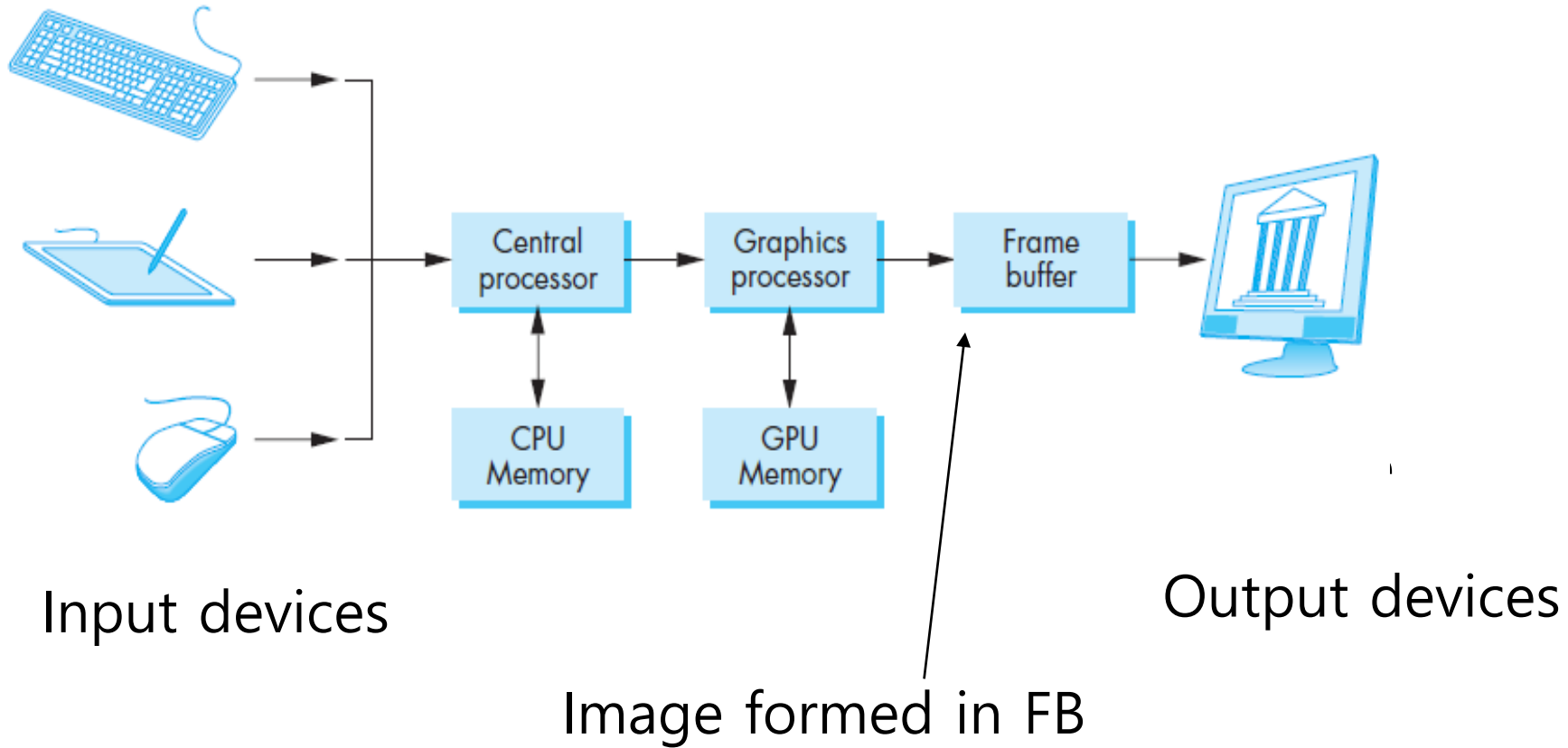
A Graphics System

- PC
  - CPU
  - Memory
  - Disk
  - Graphics card
  - Sound card
  - Peripherals: keyboard, mouse, monitor
  - Network
- Graphics card
  - GPU
  - Memory
  - Video output

A Graphics System

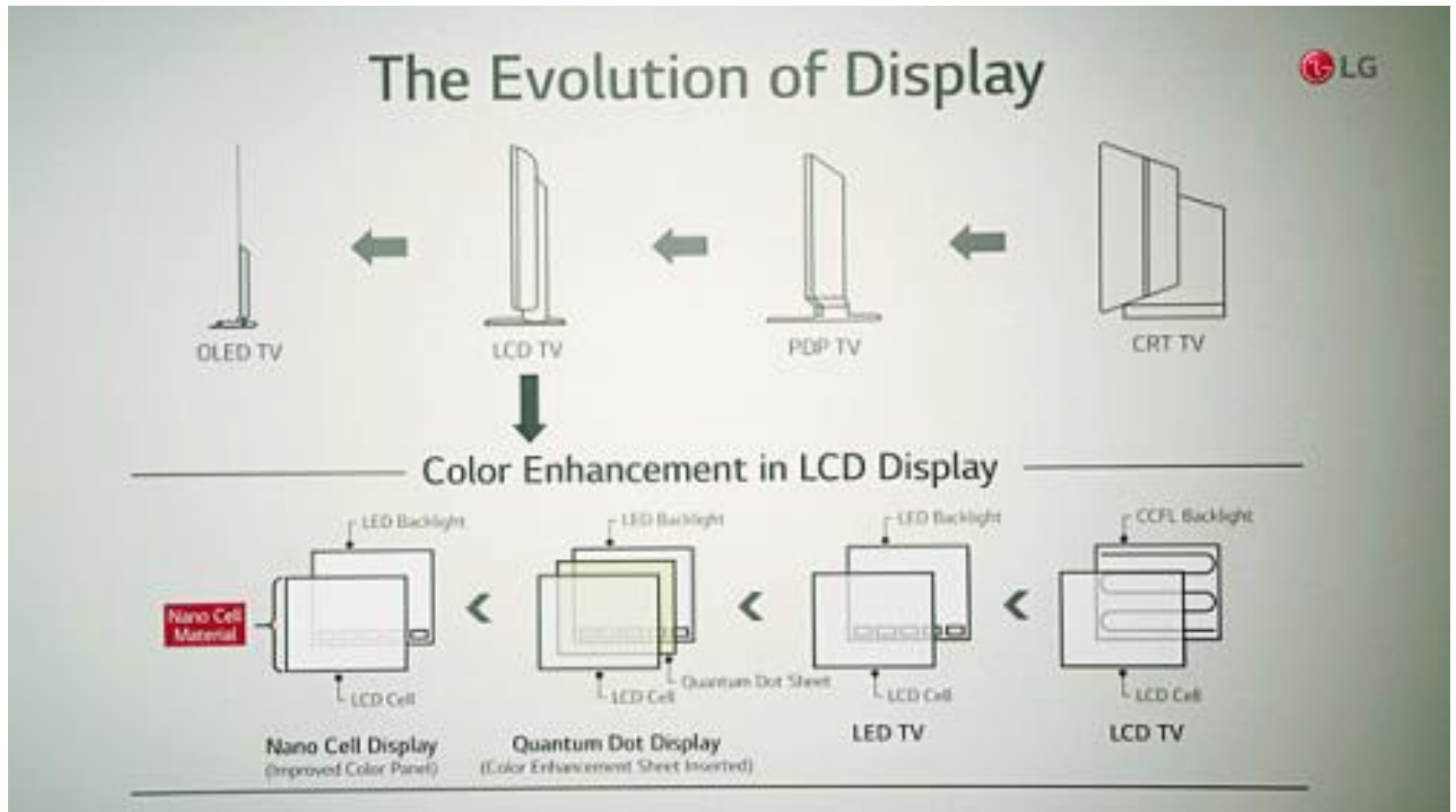Input devices

Central processor

CPU Memory

Graphics processor

GPU Memory

Frame buffer
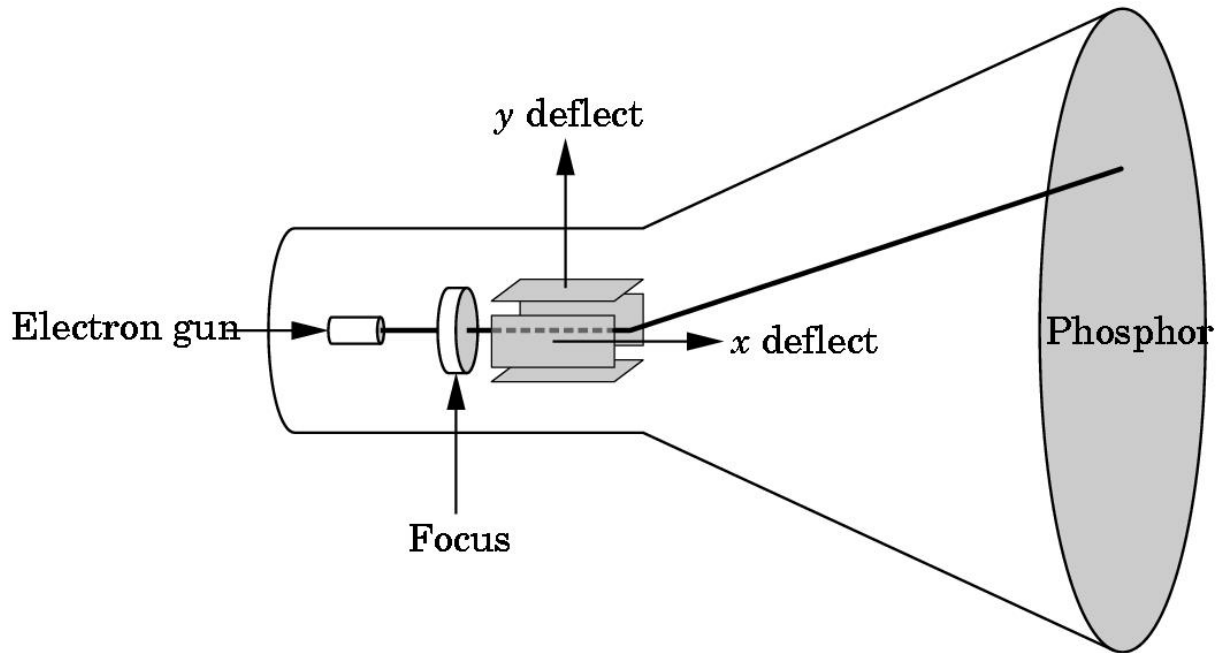
Output devices

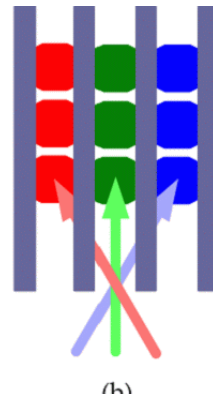Image formed in FB

Evolution of Display

Image from: https://social.lge.co.kr/product/suhd_tv_0203/
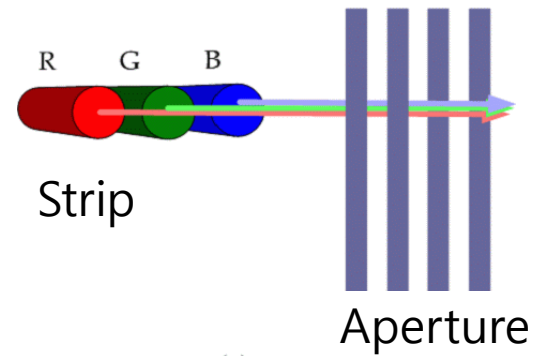
Cathode-Ray Tube (CRT)

The computer output is converted into a voltage between x,y(vertical, horizontal) deflectors by a digital-to-analog converter. When a sufficient amount of electron beam reaches the fluorescent material, light is emitted from the CRT surface. CRT is used as a line-drawing device (calligraphic) or for the frame buffer (raster mode) output.

Shadow Mask CRT

Blue gun

Green gun

Red gun

Shadow mask

Triad
Green Red
Blue

Triad   Shadow Mask   화면

R G B

Strip

Aperture

(a)   (b)
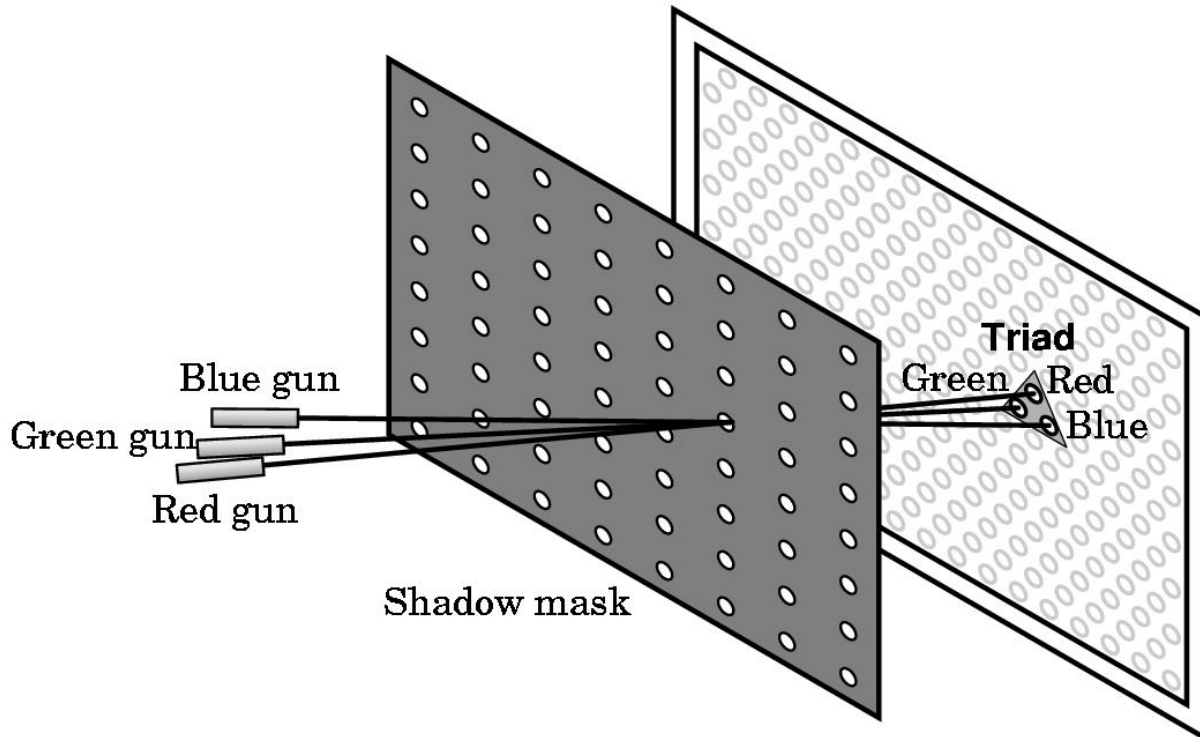
Liquid Crystal Display (LCD)

www.lgphilips-lcd.com

TFT-LCD Module Layers

D-IC(on TCP)
PCB

Bottom Cover

Top Case
LCD Panel
Diffusers & Prisms
Light Guide
Reflector
Lamp Housing
Support Main Frame
Lamp

LCD Panel Zoom

TFT-LCD Structure

Upper Glass
Polarizer
Color Filter
TFT
Lower Glass
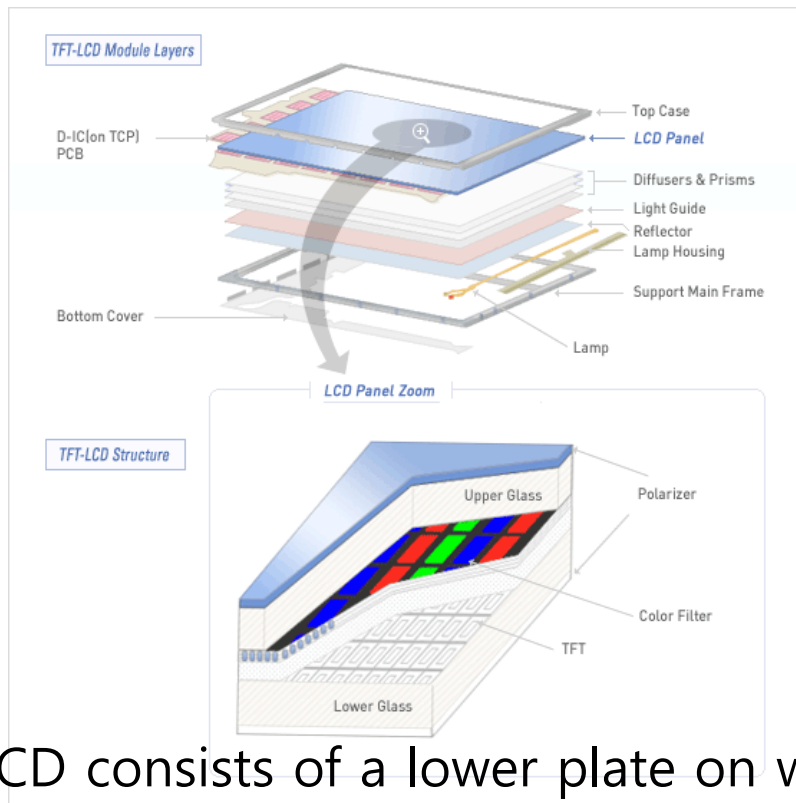
TFT LCD consists of a lower plate on which a thin film transistor and pixel electrode are arranged, an upper plate composed of a color filter and a common electrode to display colors, and a liquid crystal filled between them. Polarizing plates that linearly polarize visible light are attached to both sides of the two glass substrates, and a capacitor is formed as a liquid crystal between the upper and lower electrodes, and image information is stored there.
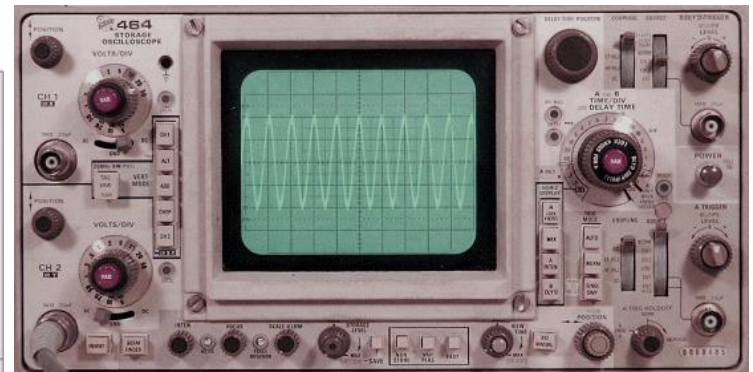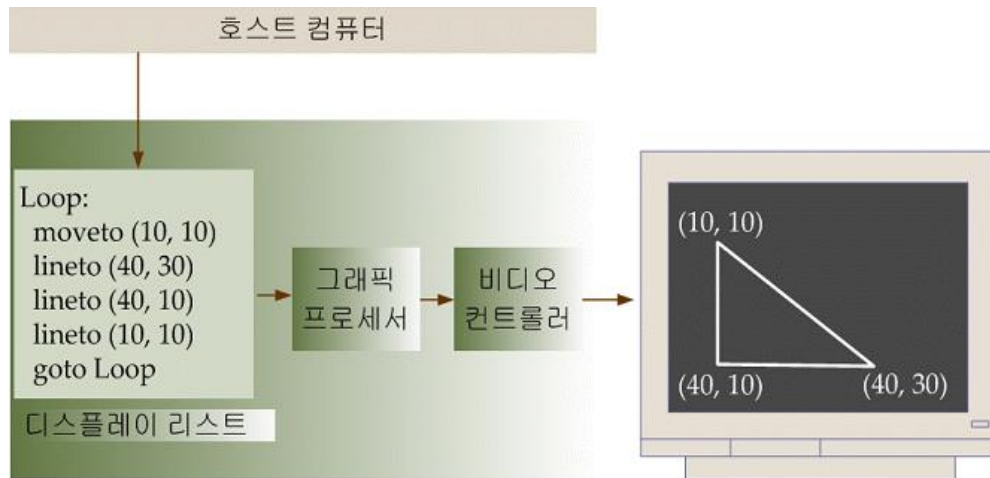
LG OLED Wave @ CES2020, Jan7-10
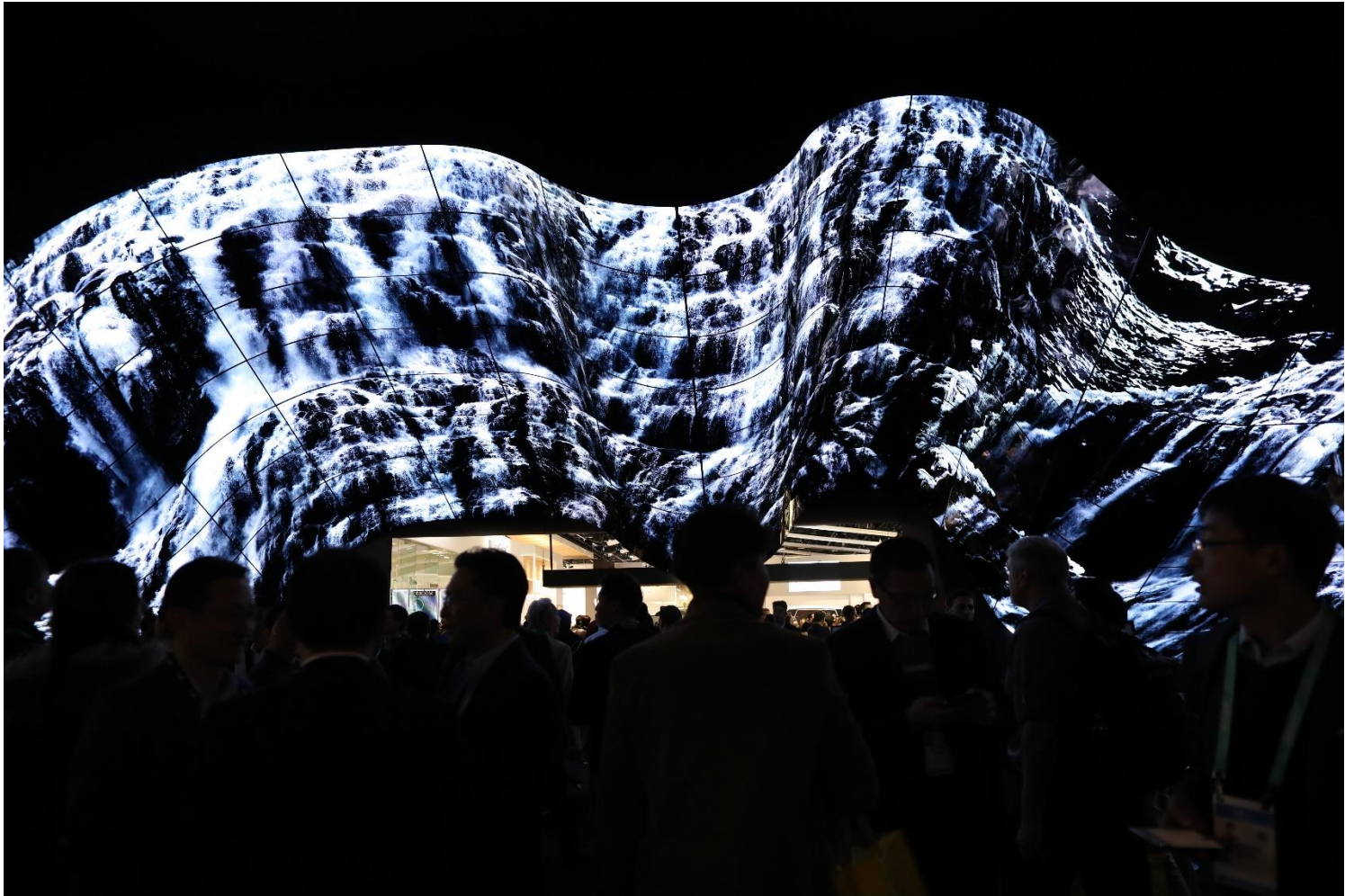
LG's Wave Display made by connecting 200 sheets of OLED Flexible Signage

Vector Graphics System

- Vector display, Calligraphic Display
- Oscilloscope, Radar, Plotter, Evans/Sutherland PS Series
- No concept of pixels
  - Infinite resolution (the width of the electron beam is the resolution)
  - No aliasing
  - No frame buffer
  - Use display list

호스트 컴퓨터

```
Loop:
  moveto (10, 10)
  lineto (40, 30)
  lineto (40, 10)
  lineto (10, 10)
  goto Loop
```

디스플레이 리스트

그래픽 프로세서

비디오 컨트롤러

(10, 10)

(40, 10)   (40, 30)
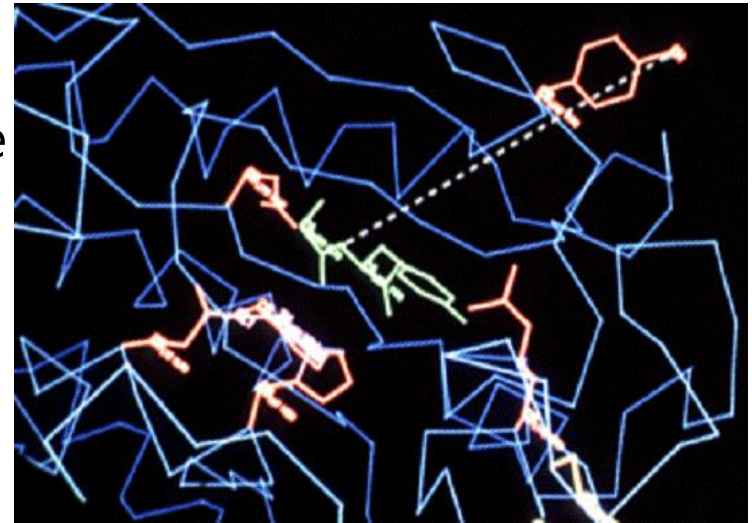
Raster-based Graphics System
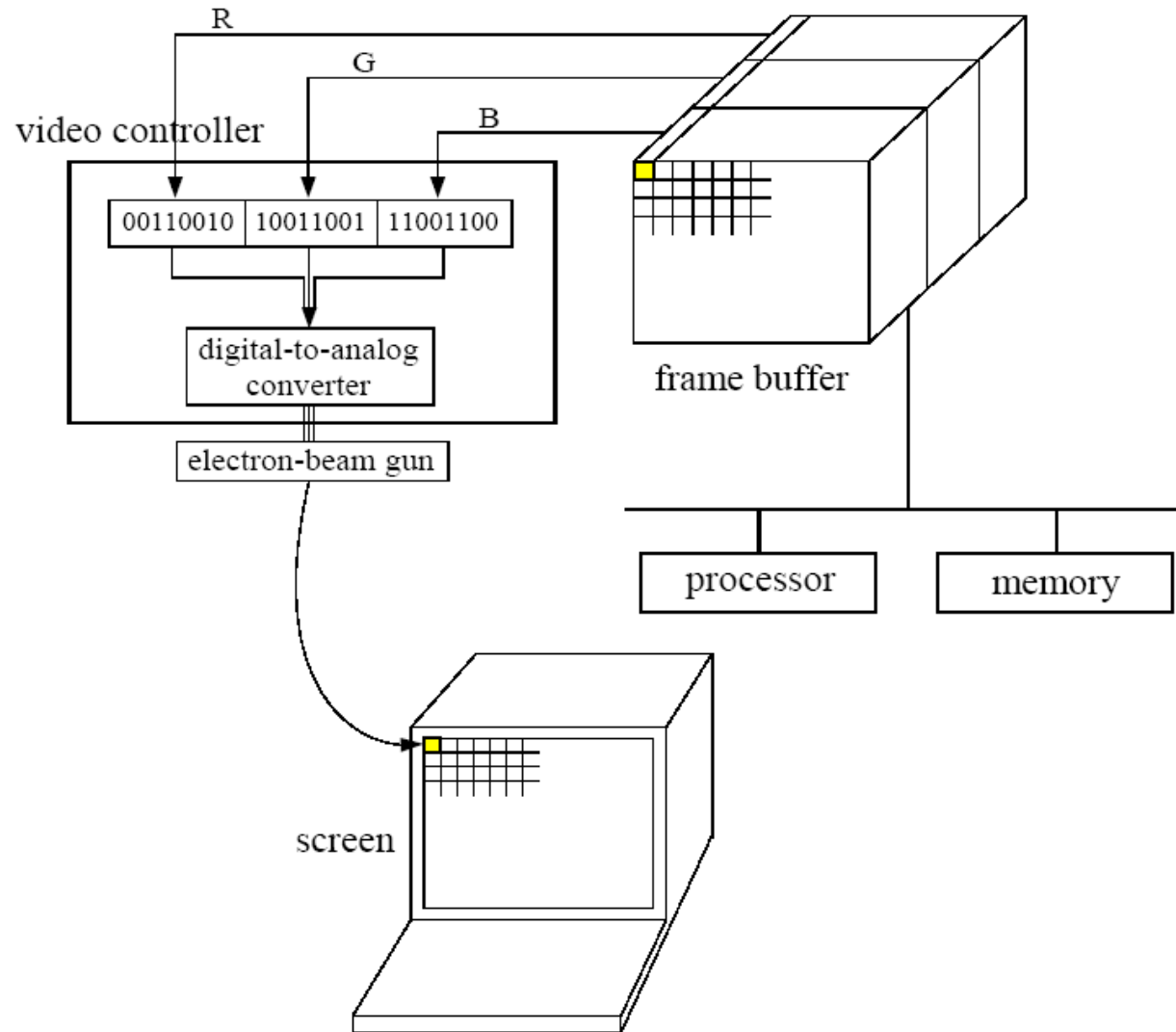
Raster-based Graphics System

- Generate as a raster, an array of pixels in a frame buffer, in a graphics system
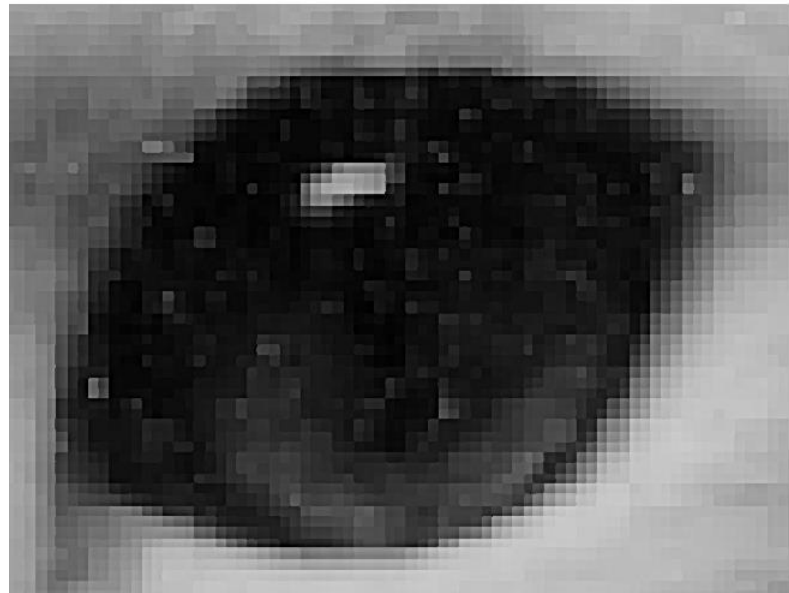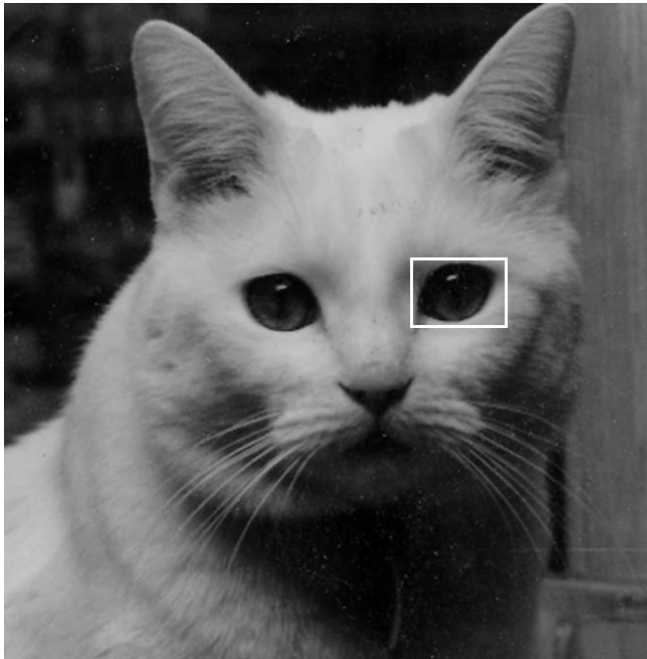
Rasterization

- Rasterization = Scan Conversion
  - Converting geometric shapes to the color and position of pixels in the frame buffer
  - From object coordinates to screen coordinates
  - From floating point coordinates to integer coordinates
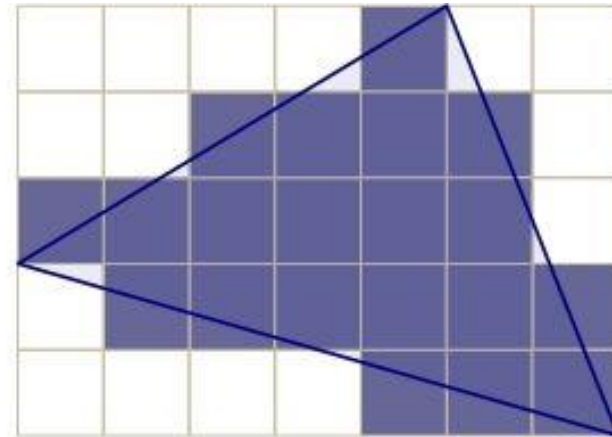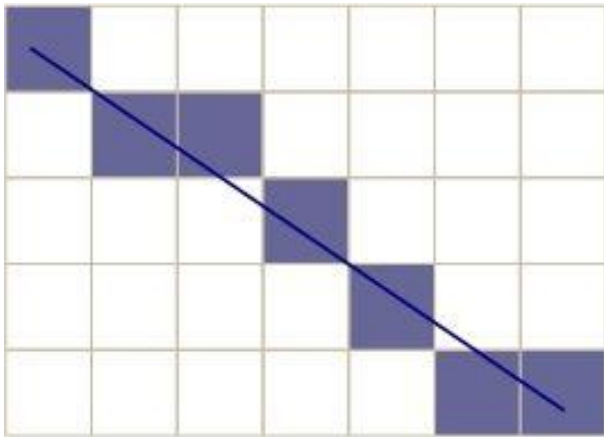
Aliasing (stair-shaped rough border)

Interlacing

- Interlacing, Interleaving
    - NTSC TV Standard: 60i, 525 Scan Line, 4:3 Aspect Ratio
    - Korea: HDTV Broadcasting(1920x1080i), 16:9 Aspect Ratio
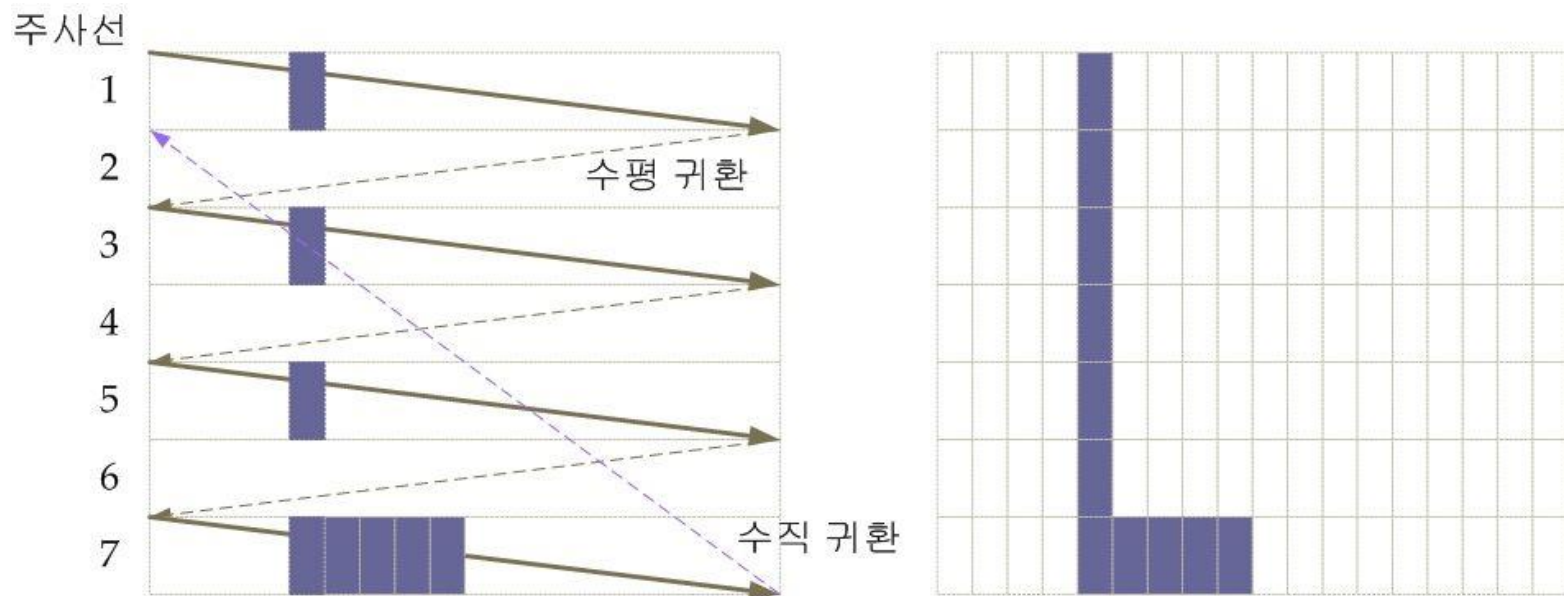
Relationship between raster image, pixel, and scan line

Interlacing

- Interlaced vs. Non-interlaced (Progressive)
  - Interlacing is a method used to display the TV screen
  - Progressive is a method used to display the computer monitor
  - Europe: HDTV Standard, 1280x720 60p

upper field

lower field
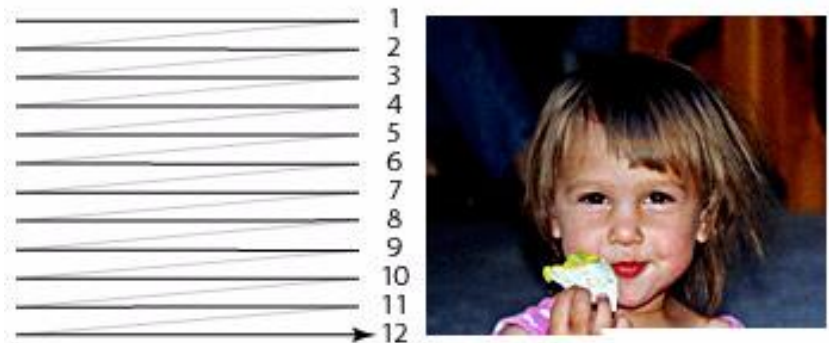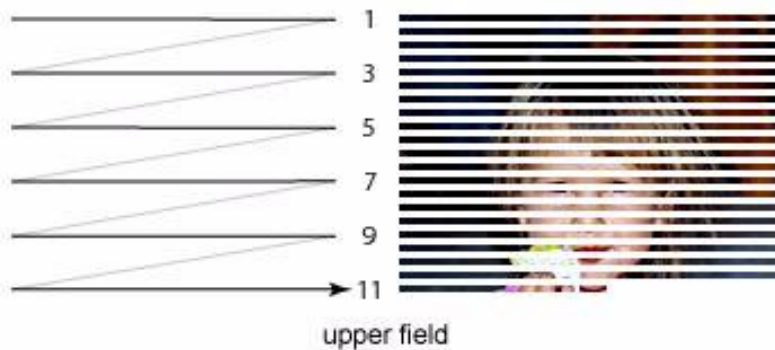
Raster Image

- Raster Image
  - The rectangular image area is divided into small areas called pixels and each pixel is painted with a color representing the area
  - An error occurs because a continuous image is expressed as an area using a finite number of pixels - this is called aliasing
- Pixel = picture element
- Frame buffer
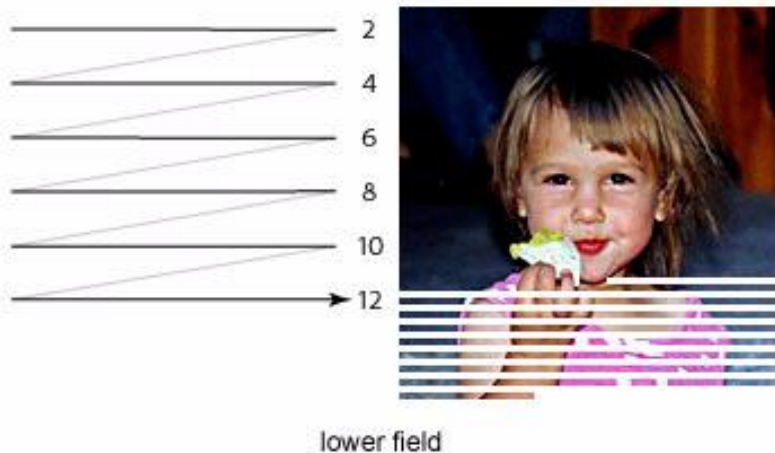 - The pixelmap data for the raster image displayed on the screen should be stored in a part of memory called the frame buffer
  - The resolution is the number of pixels in the frame buffer – 640x480, 1024x768, 1920x1080 ..
  - The depth of frame buffer determines how many colors the system can rep[resent in one pixel
    Eg., 8 bits (256 colors), 24 bits (true color), 30/36/48 bits (deep color)

Frame Buffer

- Frame Buffer refers to a video memory dedicated to graphics that stores not only raster images to be displayed on the screen, but also various kinds of information necessary to create such image
- Color buffer
    - Double buffer
    - Stereo buffer
    - Alpha buffer
- Depth buffer
- Stencil buffer
- Accumulation buffer
- Pixel buffer

Double Buffering

- Make sure the video controller always shows the final image.
- To do this, the processor calculates the contents of the image and stores it in the rear buffer
- Meanwhile, the video controller reads the contents of the front buffer and displays the image on the screen
- Double buffering produces smoother animations than single buffering
- One more buffer is required for color buffer.
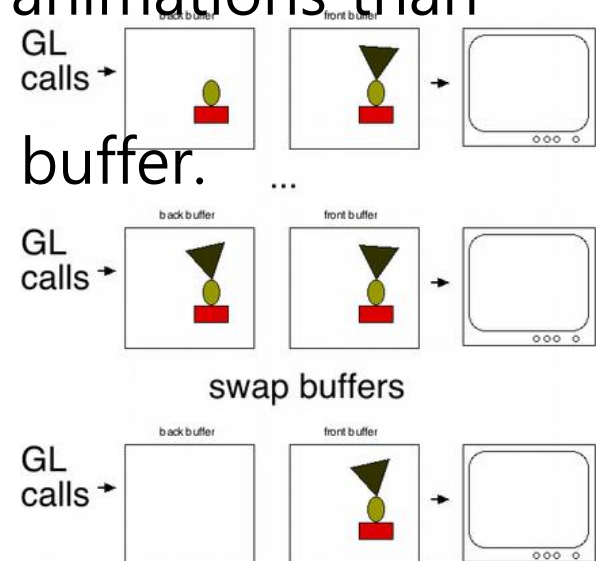
Images

- Computer-generated images are artificial in that an object does not actually exist
- The way that a computer generates an image is similar to a traditional image created by the human visual system
- Object exists in space regardless of the image generation process or observer.
- Viewer (observer) is to form an image of an object. Image formation on the retina in the human visual system and on the film in the camera.
- If there is no light, the object can not be seen in the image.
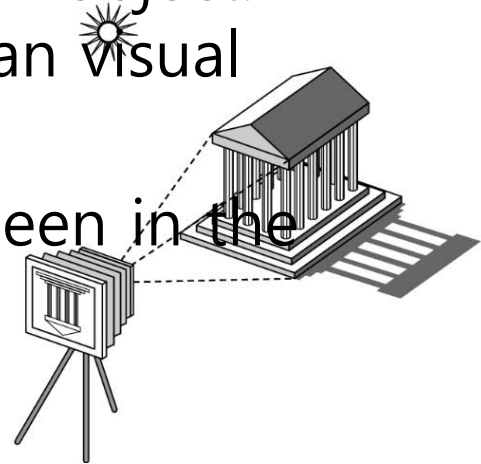
Human Visual System
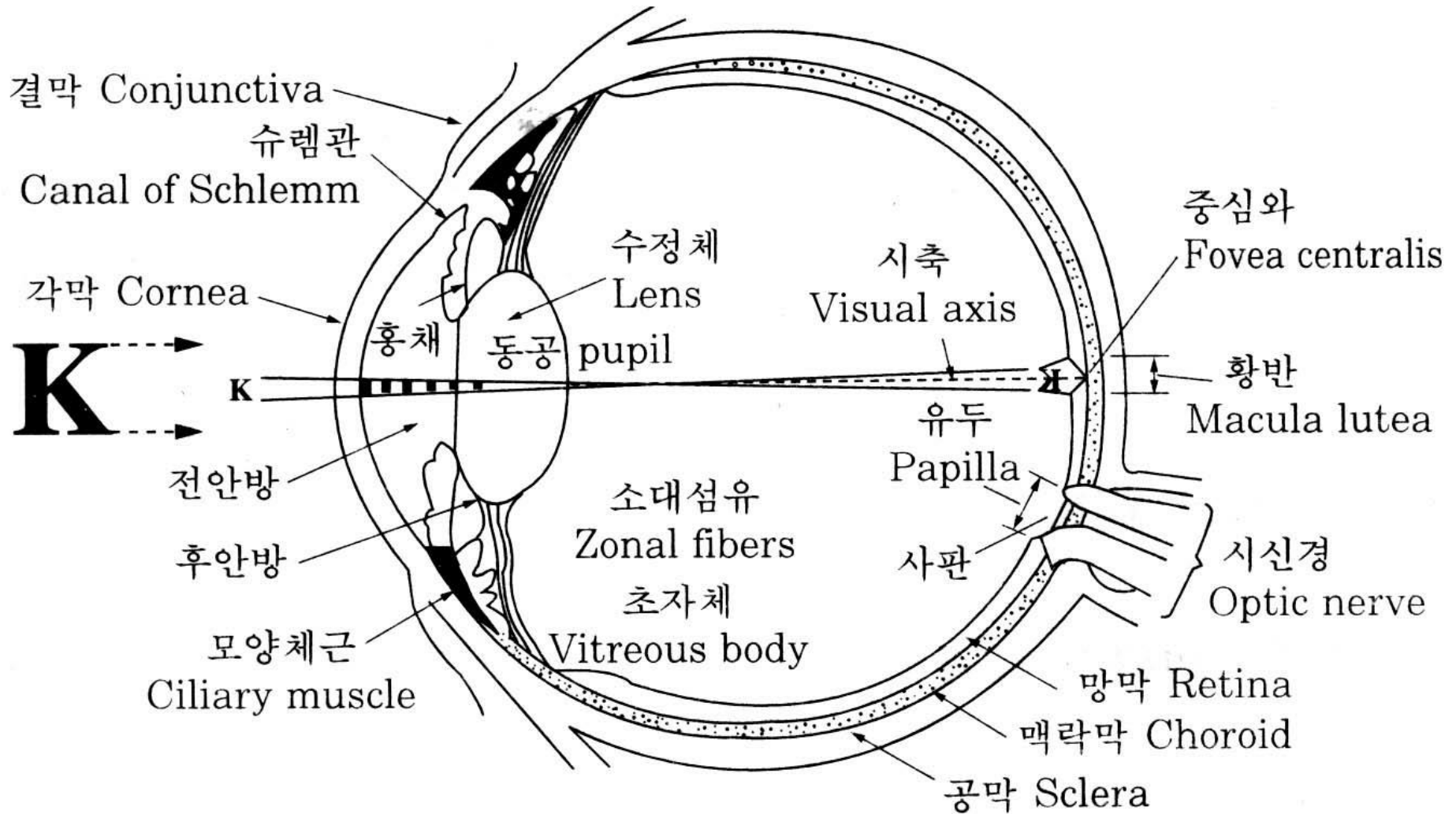
Human Eye

- Light enters the eye through the cornea.
- The iris controls the amount of light entering the eye through the pupil.
- The light passing through the pupil passes through the lens and focuses on the fovea (the photosensitive surface at the back of the eye).
- Depending on the distance between the observer and the object, the human lens causes the ciliary muscle attached to the lens to contract or relax to focus.
- When the object is close, this muscle contracts, causing the lens to bulge. When the object is distant, this muscle relaxes the flattens the lens.
- The retina acts like a film for the camera.
- The retina is composed of two photoreceptors – rods and cones.
- The retina converts light into nerve signals and sends them to the brain.

Photoreceptors (Rods & Cones)

- Rods
  - Mainly active in the dark
  - Distinguish between black and white luminance
  - If you are in a bright place and suddenly enter a dark place, you can't see anything at first and then gradually start to see the surroundings. For the first 7-8 minutes, the cone works to see the objects in the dark, and then until 40 minutes, the rod works to clearly identify the object.
  - Rod is sensitive to the blue spectrum
- Cones
  - Works in a bright environment
  - The density of cones determines visual acuity
  - There are 3 types of cones, each sensitive to the wavelength range of light corresponding to 3 primary colors (red, green, blue)
  - The cone must be activated to see the color, so there is no color vision in the dark.

Rods/Cones Distribution

- Distribution of rods and cones
 - The distribution of cones and rods is not uniform on the retina.
  - 6 to 7 million cones concentrated in the fovea.
  - The rods are concentrated from about 20 degrees away from the macula to the periphery.
- Fovea
  - Only a large number of cones exist
  - No rods
  - No S-cones (blue cones)
 - The most sensitive eyesight
- Blind Spot
  - No rods and cones
  - Only ganglion cells that transmit to the brain
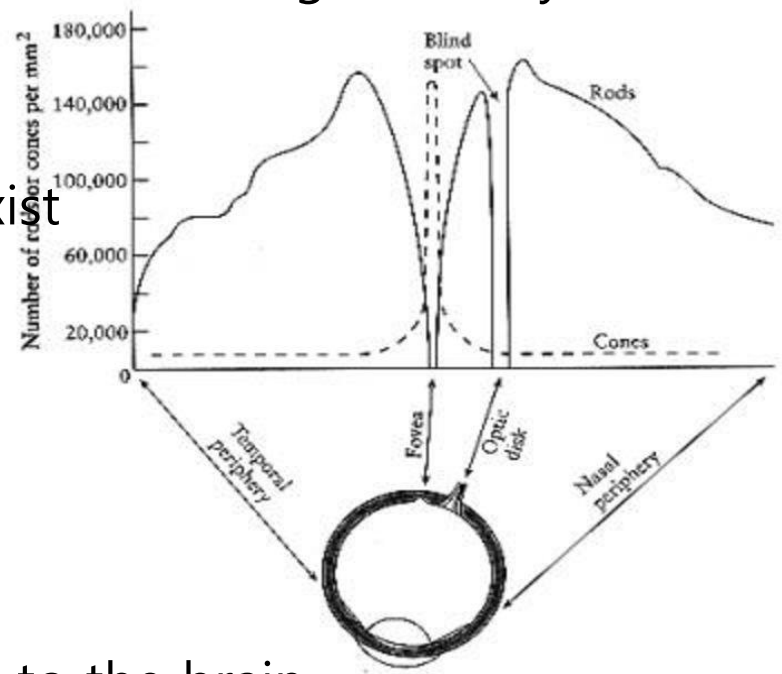
Visual Acuity

- **Minimum separable acuity**
  - The most commonly used measure of vision is minimal separable acuity, the smallest feature of the target that the eye can detect, or the smallest space between the parts of the target.
- **Vernier acuity**
  - Vernier vision is the ability to discern the lateral displacement of a line from another line, or microscopic bias.
- **Minimum perceptible acuity, Stereoscopic acuity**
  - Minimum perceptible acuity is the ability to discern a point (such as a round point) from the background. Also, the ability to discern the difference between a single object with depth is called stereoscopic acuity.
- **Looking at a 1280x1024, 17'' monitor from 2 feet away provides 1.4 arc-minutes per pixel.**

Color Perception
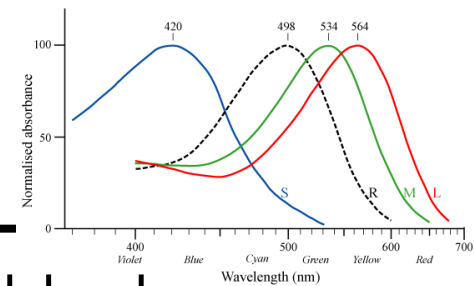
- Visible spectrum, which can be recognized by humans, spreads between 400 nm(purple) and 700 nm (red).

- Objects reflect multiple wavelengths except in extreme cases, so the same point on the retina is stimulated by them.

- There are three cones, S, M, and L, which are sensitive to the wavelength range of light corresponding to blue, green, and red, respectively.

- The perception of color is the result of the simultaneous action of these three cones.

- Color blindness is a phenomenon that occurs when these three cones are lacking.

- Color television represents color by an additive mixture of red, green, and blue dots.

Chromatic Color
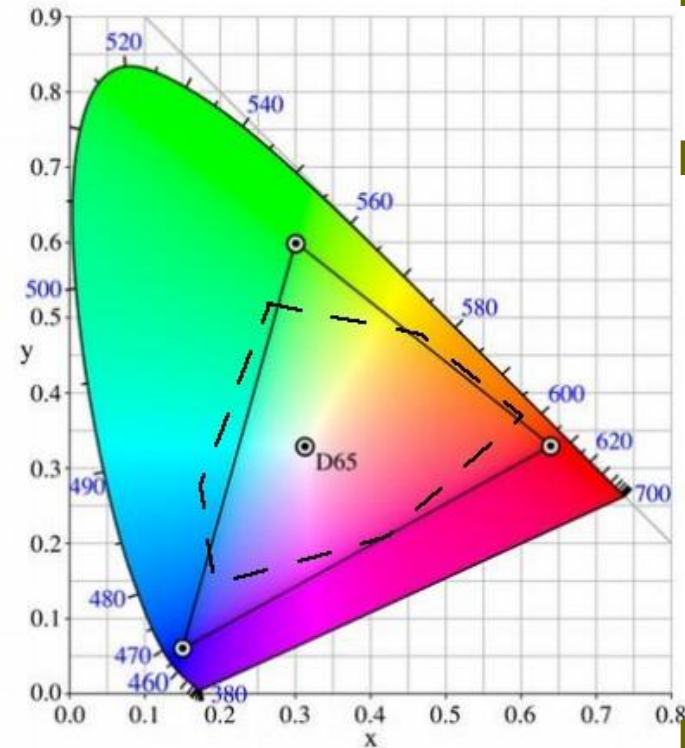
- ❑ Hue
  - ■ Color visual experience
- ❑ Saturation
  - ■ Saturation is the degree to which the purity of the color decreases due to white/grey
  - ■ Dark colors (red, blue) are those with high saturation. Far from gray.
  - ■ Pastel tones (pink, sky blue) are those with low saturation. Getting closer to gray.
- ❑ Brightness
  - ■ The physical intensity of the light stimulus determines the sensed brightness.
  - ■ The dimension of brightness varies from black to white where there is no color and the brightness is at its maximum.

Color Model

- Which model will you use to express colors?
    - RGB
    - CMY
    - HSV/HSB
   - YUV/YIQ – PAL/NTSC Television

RGB

- Three primary colors of light, suitable for color display
- In the RGB color model, each pixel value is expressed by adding (RED, GREEN, BLUE) values
  - n_R: # of bits for R channel
  - n_G: # of bits for G channel
  - n_B: # of bits for B channel
  - $n = n_R + n_G + n_B$
  - $2^n = 2^{(nR + nG + nB)}$ colors can be expressed
- Examples
  - Black (0, 0, 0), **White (1, 1, 1)**
  - Red (1, 0, 0), Green (0, 1, 0), Blue (0, 0, 1)
 - Cyan(0, 1, 1), Magenta (1, 0, 1), Yellow (1, 1, 0)
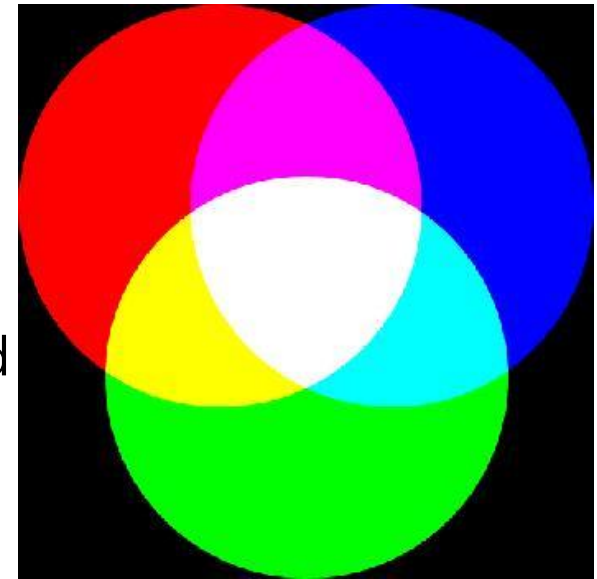
CMY

- Three primary colors of color, suitable for printing
- In the CMY color model, Cyan, Magenta, Yellow which are the complementary colors of RGB. A method of subtracting RGB from white color.
  - Cyan = 1 − red (remain only green & blue)
  - Magenta = 1 − green (remain only red & blue)
  - Yellow = 1 − blue (remain only red & green)
- Examples
  - **Black (1, 1, 1)**, White (0, 0, 0)
  - Red (0, 1, 1), Green (1, 0, 1), Blue (1, 1, 0)
  - Cyan (1, 0, 0), Magenta (0, 1, 0), Yellow (0, 0, 1)
- RGB/CMY conversion
  - CMY = (1, 1, 1) − RGB
  - RGB = (1, 1, 1) − CMY
- CMYK is mainly used in printing by adding (Black, K)
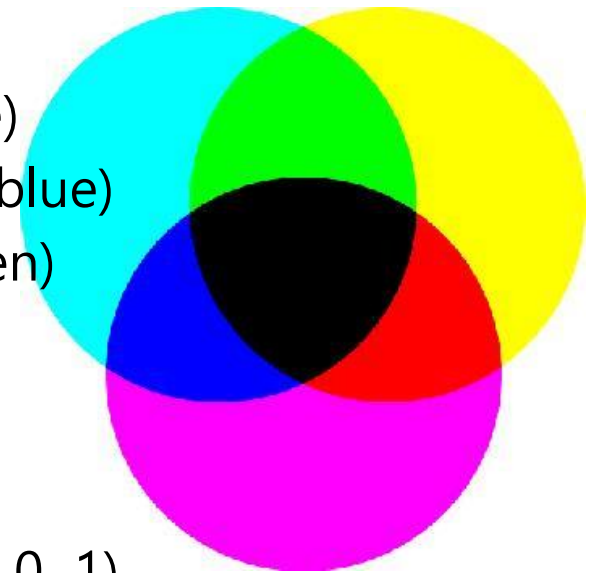
HSV/HSB

- The HSV color model is Hue, Saturation, Value/Brightness
    - Color ranges from 0 to 360 degrees
        - 0 - red, 120 - green, 240 - blue
    - Saturation is a radius in the range of 0 to 1
        - 0 – Contrast of brightness (achromatic color)
        - 1 – Color is 100% saturated at the top edge of conical base
    - Brightness is the position on the z-axis
   - 0 - Black
        - 1 - White
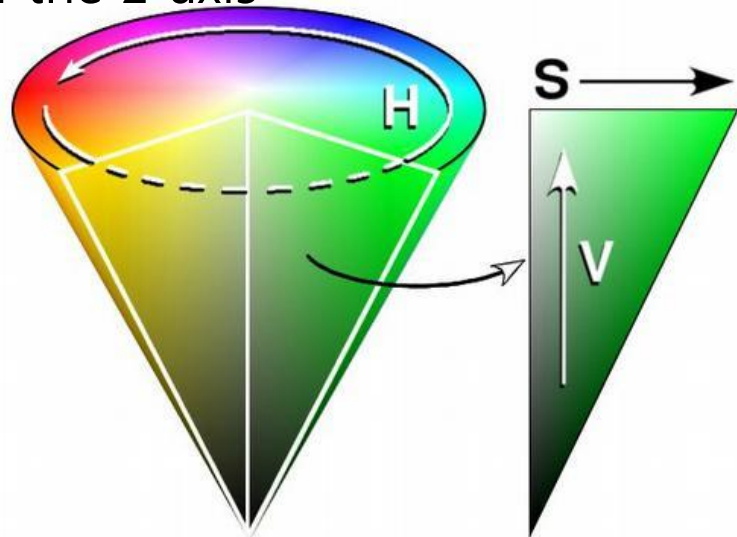
YUV/YIQ

- The YUV color model is a method of converting an RGB into a luminance (Y) representing the contrast of an image and two chrominance (U, V) on TV
  - Y: Brightness expressed as a number from 0 to 1
  - U: The degree of blue is expressed as a number from -0.5 to 0.5
  - V: The degree of red is expressed as a number from -0.5 to 0.5
- RGB->YUV
  - Y = 0.299 R + 0.587 G + 0.114 B
  - U = -0.147 R − 0.289 G + 0.436 B
  - V = 0.615 R − 0.515 G − 0.100 B
- YUV->RGB
  - R = Y + 1.140 V
  - G = Y − (0.396 U + 0.581 V)
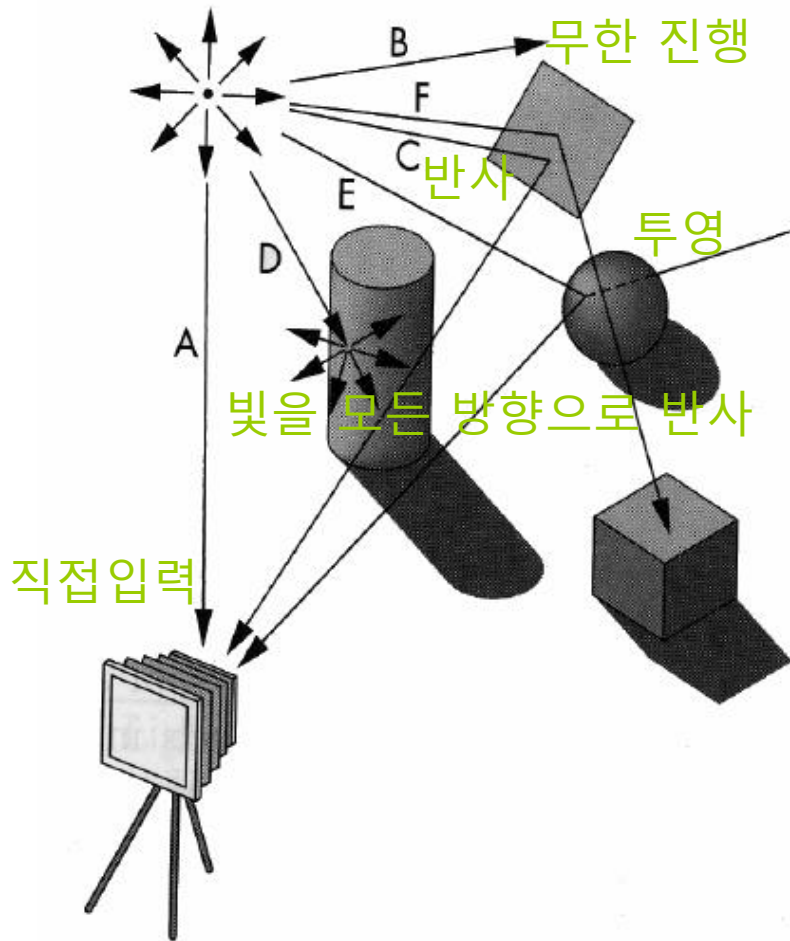 - B = Y + 2.029 U
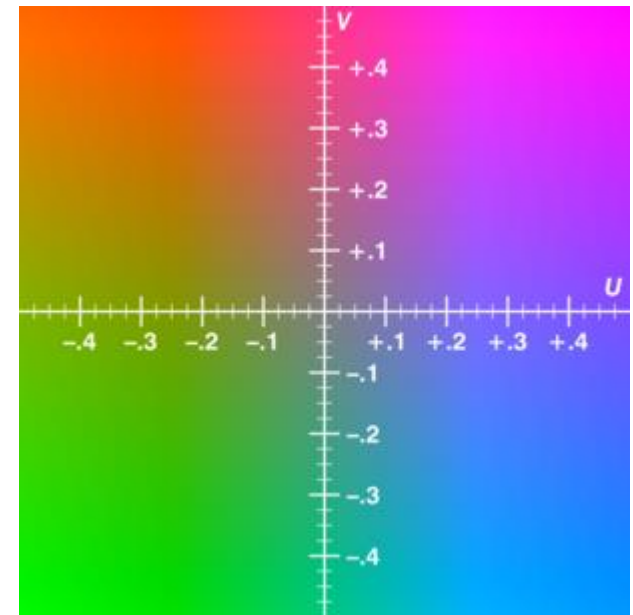
U-V Color Plane

Luminance

- Color brightness
- Convert from RGB color to brightness
  - NTSC standard brightness = 0.299 * R + 0.587 * G + 0.114 * B
    - According to NTSC standard
  - Average brightness = 0.33 * R + 0.33 * G + 0.33 * B
   - Converting from RGB to HSV
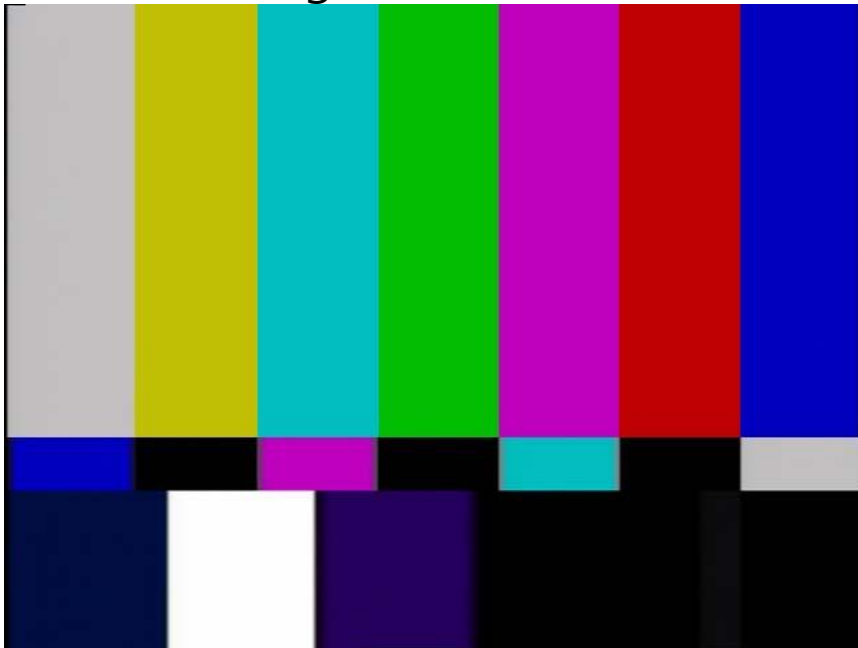
Synthetic Imaging Process

- A point light source emits light in all directions from one point.
- The viewer is a camera.
- A ray starts at a point and runs infinitely in any direction.
- Ray tracing or photo mapping is a technique created by tracking all the processes of photons protruding from a light source, colliding with an object, and then entering the eye.
- Radiosity is best suited for objects in which light rays input to a plane are reflected equally in all directions. Energy based technique.

Pinhole Camera

- Pinhole camera is a box with a small hole on one side of box and a film on the other side of the inside.
- $(x_p, y_p, -d)$ is the projected point of (x, y, z).
- The camera's filed of view is the angle created by the largest object that can be formed on the film side.
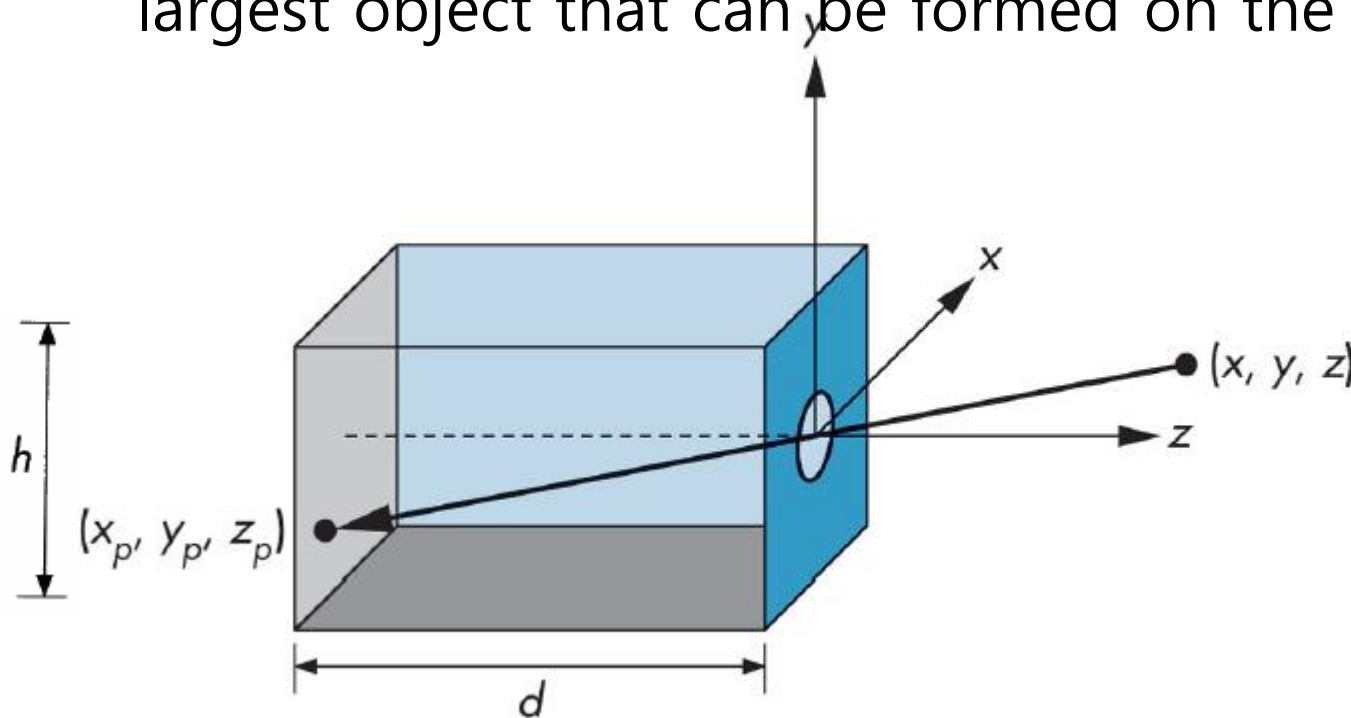
$$\theta = 2\tan^{-1}\frac{h}{2d}$$
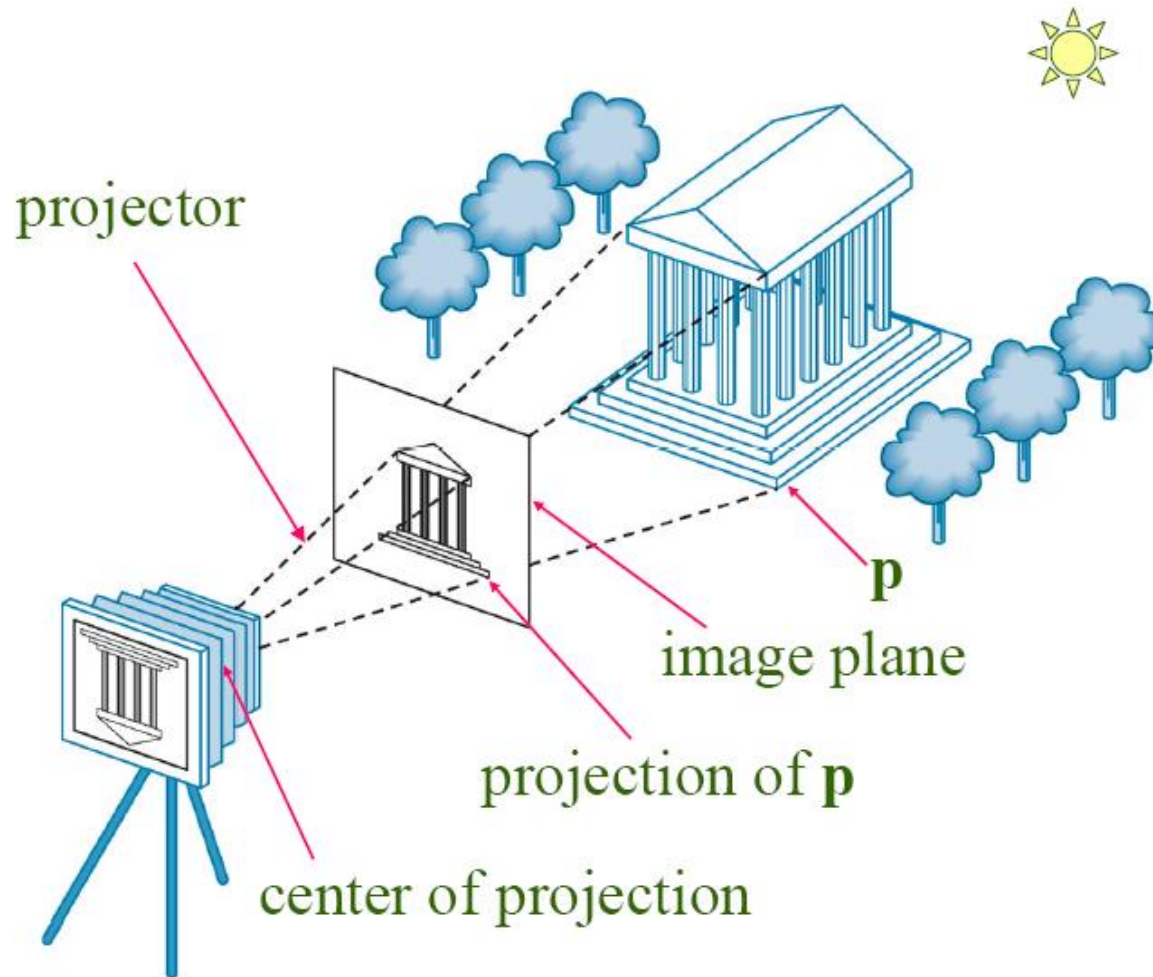
$$x_p = -\frac{x}{z}d$$

$$y_p = -\frac{y}{z}d$$

Synthetic-Camera Model

- Moving the image plane forward in the pinhole camera model
- Clipping window
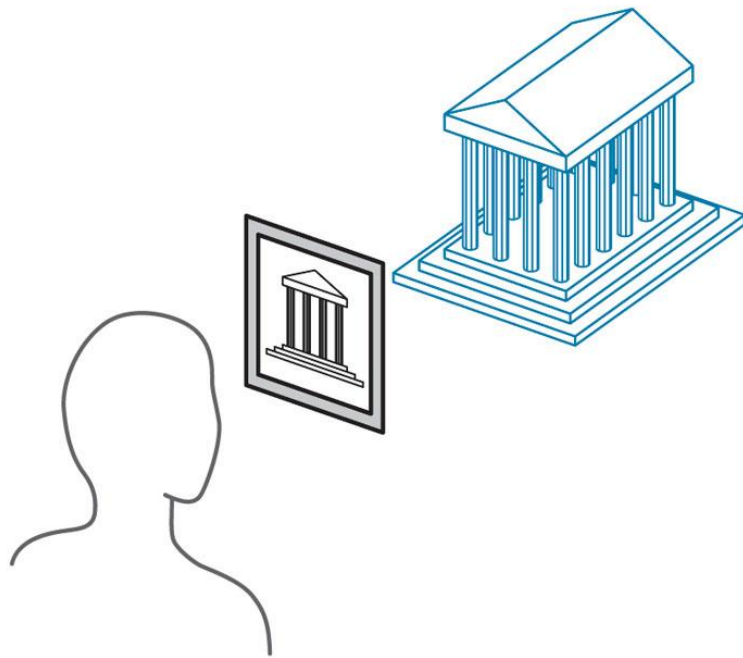 - In the composite camera, the limitation of image size according to the field of view should be considered.

COP (Center of Projection)

Image plane in front of the camera
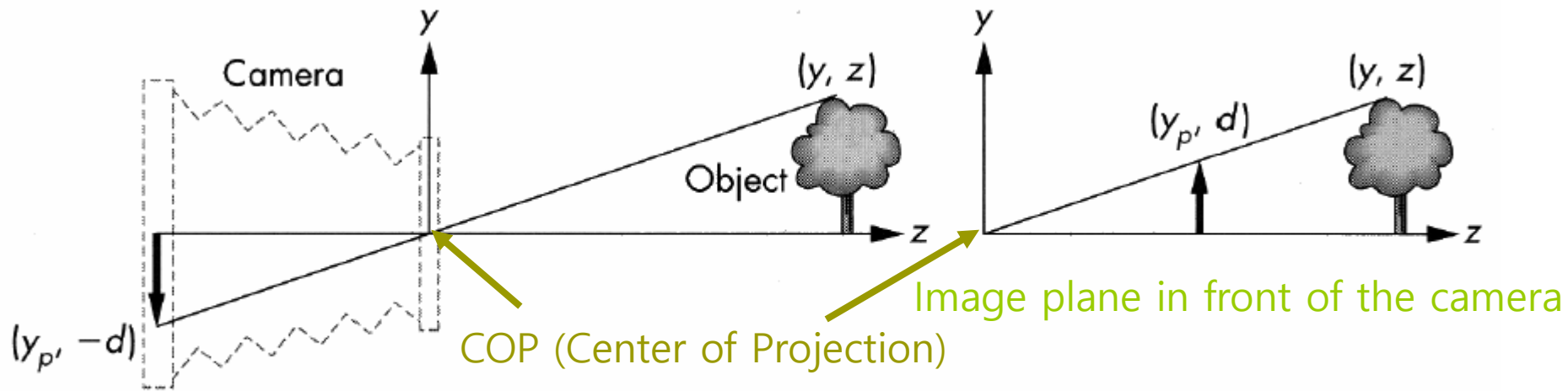
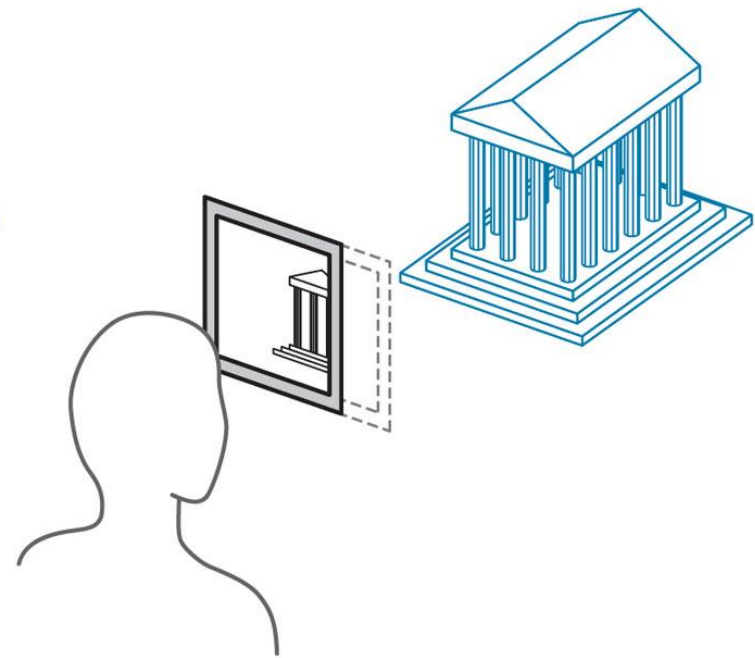Video created on the back of the camera
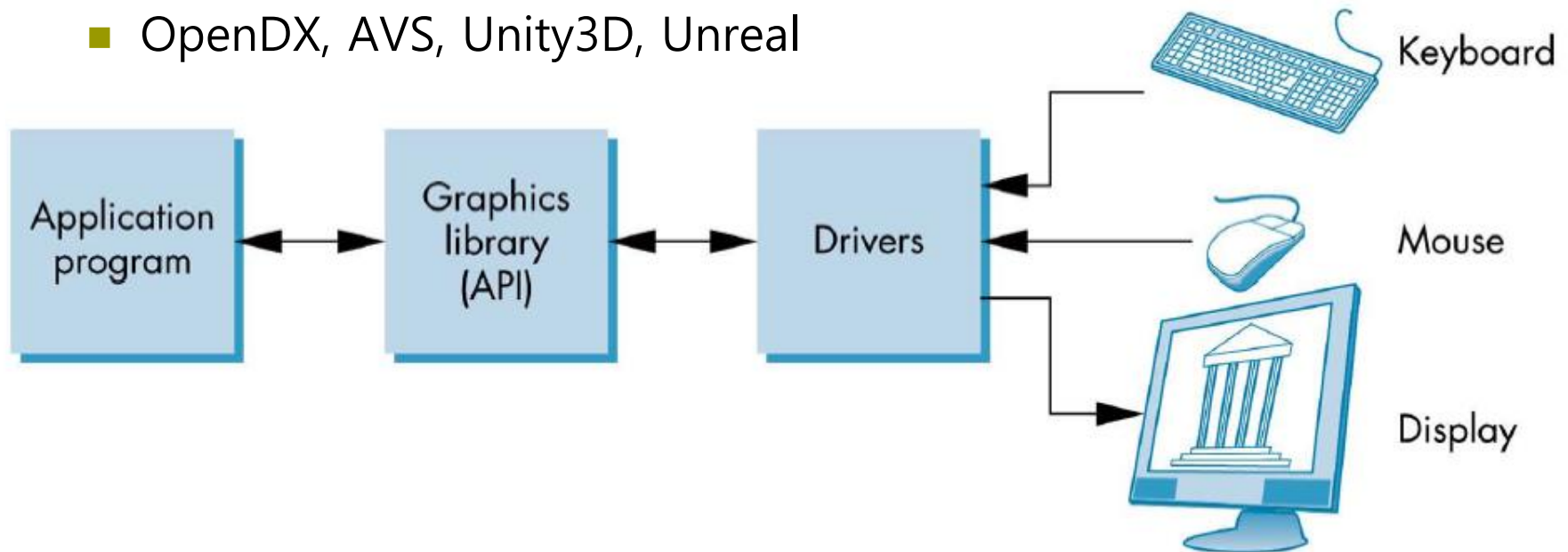
Synthetic-Camera Model

Clipping

Initial position of clipping window

Moving the clipping window

3D Graphics API

- ☐ Low-level graphics libraries
  - ■ OpenGL, Direct3D
- ☐ Scene graph libraries
  - ■ SGI Performer, Open Inventor, Open Scene Graph, Java3D
- ☐ Scientific visualization & advanced graphics toolkits
 - ■ OpenDX, AVS, Unity3D, Unreal

Low-level 3D Graphics API

- Basic commands:
    - Points, lines, polygons, curves and surface geometric modeling
    - Position, rotation, scaling
    - Color
    - Light sources
    - Material properties
    - View – camera position: center of projection), camera coordinate system, size of the image, height and width of the back of the camera
    - Texture loading

Scene Graph API

- The scene graph is a tree structure used to represent graphics
- Node represents group, transformation, light, geometry, etc
- Key elements:
    - Standard data structures for geometry & graphics state
    - Automatic, optimized rendering
    - View culling
    - Level of detail
    - Model loaders
    - Math: vectors, matrices, quaternions
   - Intersection testing
    - Multiprocessing
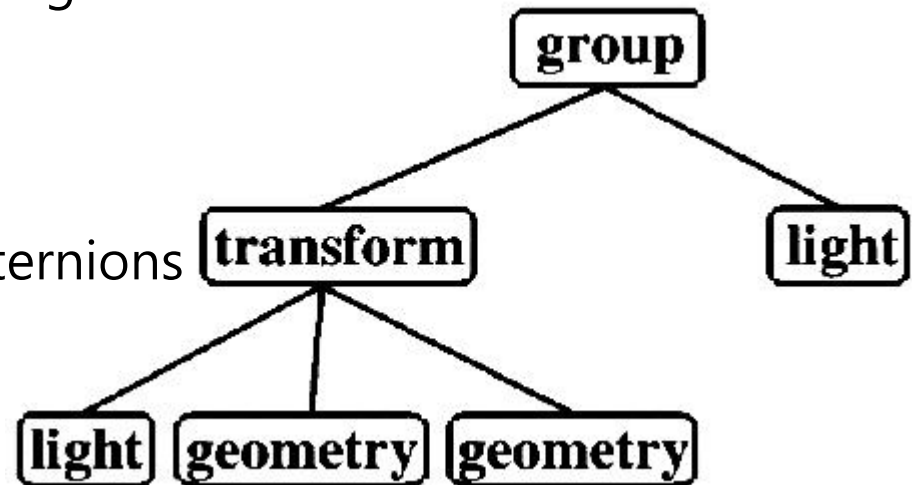
Graphics Pipeline

- The graphics pipeline process data in PC memory
- CPU executes program to process graphics instructions
- Commands and data are sent to the graphics card
- Images are rendered in the graphics card memory
- Interface connecting CPU and graphics card
  - PCI
  - AGP
  - PCI Express
- Interface connecting graphics card and display
  - VGA (D-SUB)
  - DVI
  - Composite, S-Video
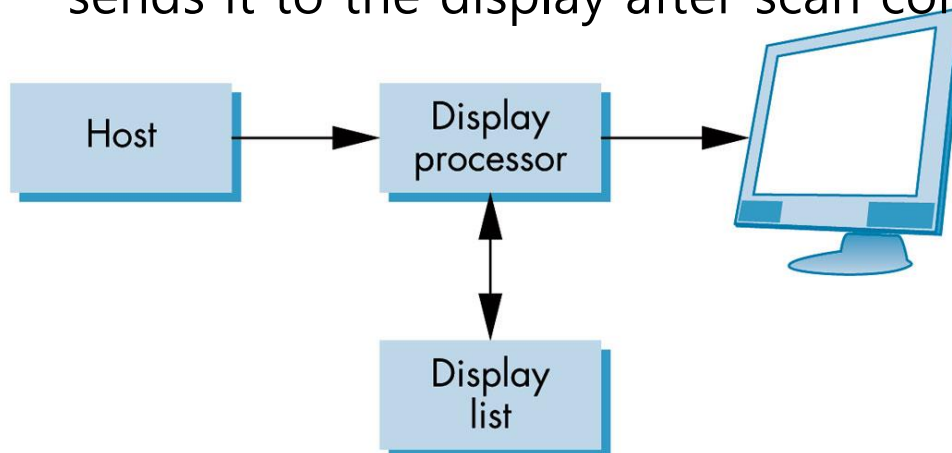 - HDMI
  - DP

# Graphics Architecture

- Early graphics system
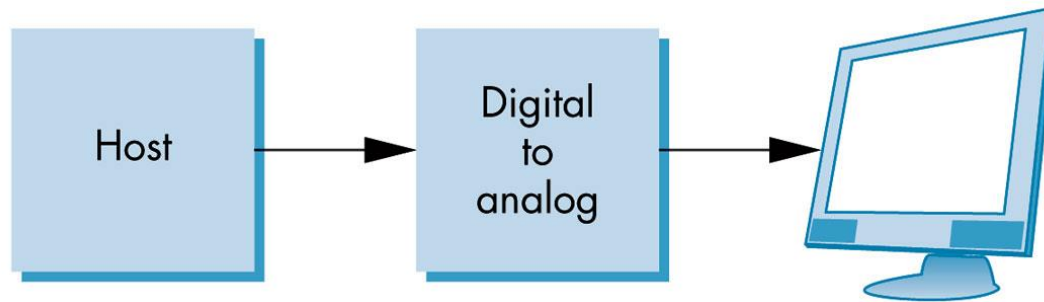
- Display processor structure
  - The display processor executes the program in the list and sends it to the display after scan conversion.

Pipeline Architecture

□ Graphics pipeline structure
  - Vertex processing
  - Clipping and primitive assembly
  - Rasterization
  - Fragment processing

Vertices → Vertex processor → Clipper and primitive assembler → Rasterizer → Fragment processor → Pixels
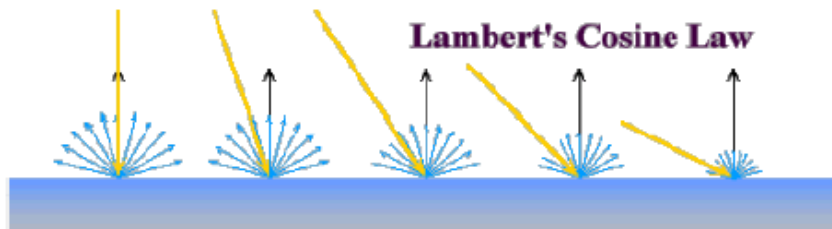
Application

Display
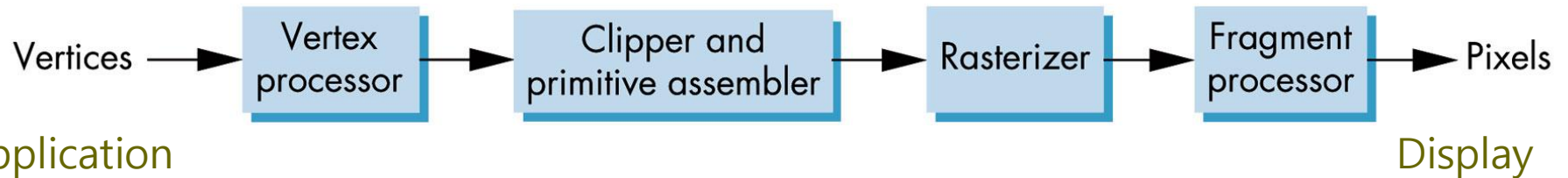
Vertex Processing

- Process coordinate transformation of each vertex and calculate color

- Matrix transformation
 - Model transformation
  - Viewing transformation
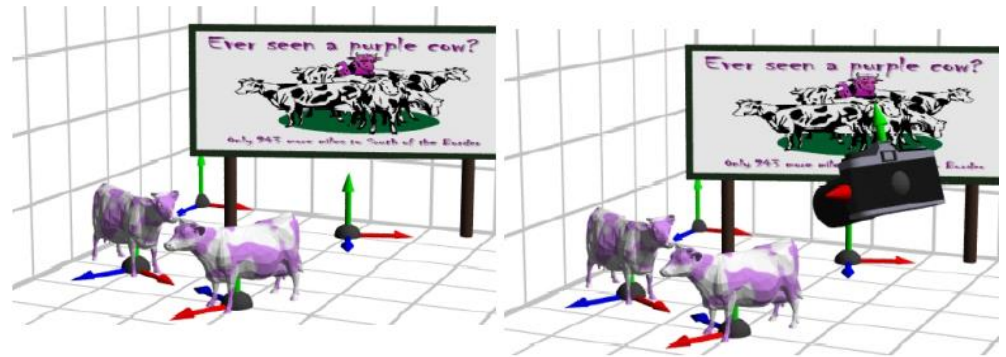
- Calculate color using a physical shading model that considers the characteristics of the light source and the physical characteristics of the object surface.

Clipping and Projection

- Projection determines which point on the 2D screen is a point in the 3D space that constitutes an object when the observer composes the composition.
  - Perspective projection
  - Parallel projection
- Objects projected outside the window are clipped without appearing as an image by placing a pyramid like clipping volume in front of the camera.

Angle of view
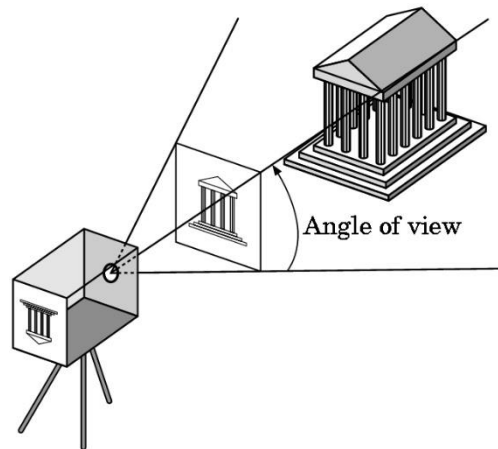
Primitive Assembly

- Clipping is done in units of geometry primitives rather than in units of vertices
- In the clipping phase of the pipeline, a set of vertices is assembled into units of geometry primitives as shown below before clipping occurs.
  - Line segments
  - Polygons
  - Curves and surfaces

Rasterization

- The primitives from the clipper are still represented as vertices, which must be converted to pixels in the frame buffer.

- The output of the raster is a set of fragments for each geometry primitives

- Fragments are tentative pixels that convey color and position information

- Fragment is depth information for determining whether the current fragment lies behind an already rasterized fragment for a given pixel.

Fragment Processing

- Take the fragments generated by the raster and update the pixels in the frame buffer.
- The color of the pixel corresponding to the fragment is read from the frame buffer or mixed with the color of the fragment to give a translucent effect.
- The color of the fragment is changed to texture mapping or bump mapping, or interpolated with the color of the vertex.
- The fragment close to the camera can make other fragment invisible.
  - Hidden-surface removal

Programmable Pipeline

- GPU (Graphics Processing Unit) recently announced by graphics card manufacturers such as NVIDIA and ATI.

- Part of the rendering pipeline allows programmers to program the way they want through vertex shaders and pixel/fragment shaders.

- Various real-time rendering effects that were not possible in the past can be flexibly created.
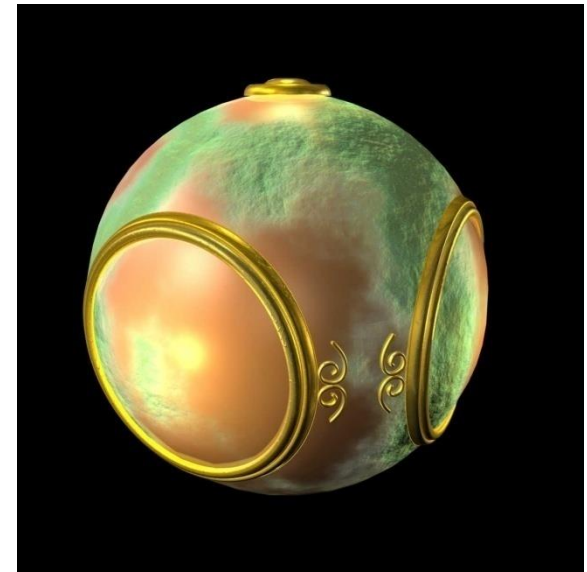
Computer Graphics: 1980-1990

Realism comes to computer graphics
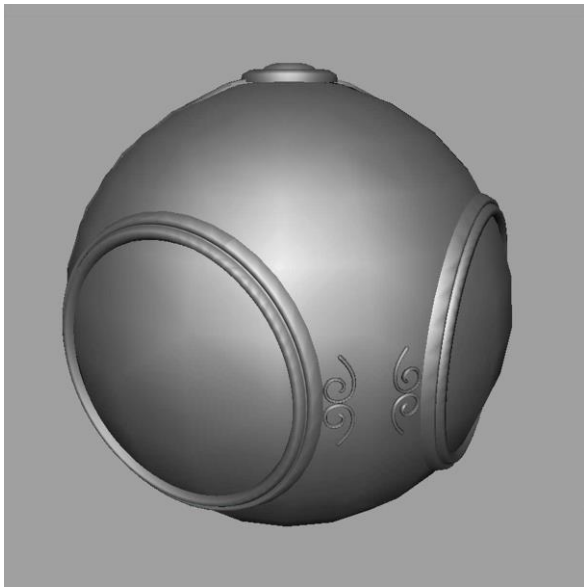
Smooth shading



Environment mapping

Bump mapping

Computer Graphics: 1980-1990

- Special purpose hardware
  - Silicon Graphics geometry engine
    - VLSI implementation of graphics pipeline
- Industry-based standards
  - PHIGS
  - RenderMan
- Networked graphics: X Window System
- Human-Computer Interface (HCI)

Computer Graphics: 1990-2000

- OpenGL API
- Completely computer-generated feature-length movies (Toy Story) are successful
- New hardware capabilities
  - Texture mapping
  - Blending
  - Accumulation, stencil buffers
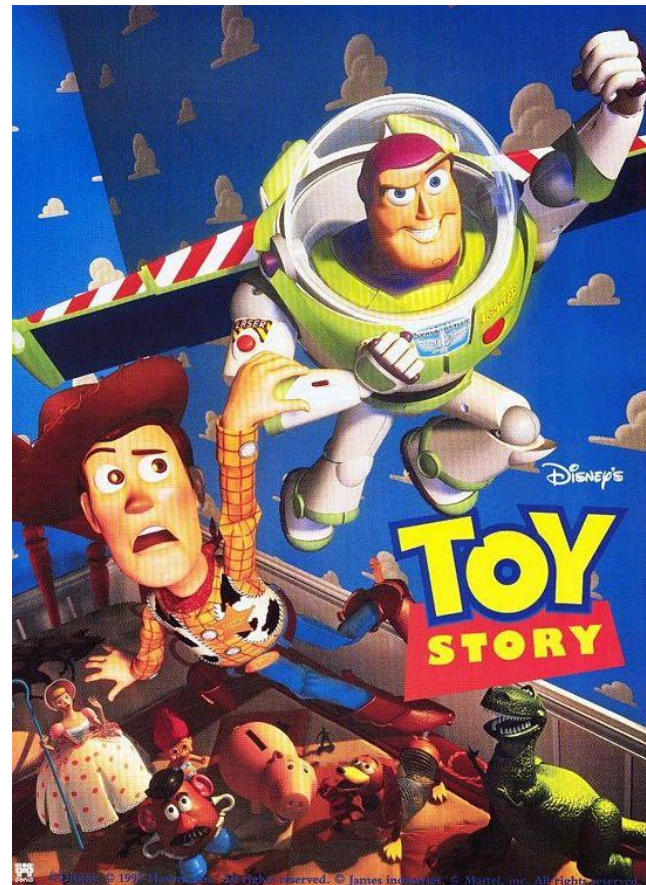
Computer Graphics: 2000-

- Photorealism & Non-Photorealism
- Graphics cards for PCs dominate market
  - Nvidia, ATI
- Game boxes and game players determine direction of market
- Computer graphics routine in movie industry
  - Maya, Lightwave
- Programmable pipelines
  - Cg, GLSL, HLSL
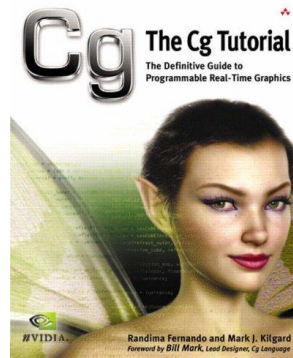
Computer Graphics: 2000-

- Virtual Reality
  - Oculus Rift (2012)
  - HTC Vive (2016)
  - Sony Playstation VR (2016)
  - Oculus Quest 1(2019), Meta 2(2020), Meta 3(2023)
- Augmented Reality
  - Google Glass (2013)
  - Pokemon GO (2016)
  - Magic Leap AR (2018)
- Mixed Reality
  - Microsoft HoloLens (2015)
  - Samsung Gear VR (2015)
  - Apple Vision Pro (2024)