# Overview of Computer Graphics

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- What is Computer Graphics?
- Developmental History
- Applications Areas
- Basic Graphics System
- Elements of Image Formation
  - Objects
  - Viewer/Camera
  - Light source(s)
- Color Models

# What is Computer Graphics?

- Creation, Manipulation, and Storage of geometric objects (modeling) and their images (rendering) with a computer
- Display those images on screens or hardcopy devides (animation…)
- Other:
  - Image processing, Computer Vision,
  - CAD, GUI
  - Haptics, Virtual Reality,…

# What is Computer Graphics?

- Example
  - Where did this image come from?
  - What hardware/software did we need to produce it?

Answer

  - Application: The object is an artist’s rendition of the sun for an animation to be shown in a domed environment (planetarium)
  - Software: Maya for modeling and rendering but Maya is built on top of OpenGL
  - Hardware: PC with graphics card for modeling and rendering

# Developmental History

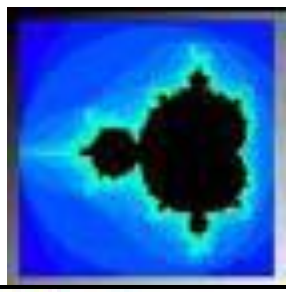

- 1885 - CRT (Cathode Ray Tube)
- 1887 - Edison patents motion picture camera
- 1888 - Edison and Dickson record motion picture photos on a wax cylinder


- 1926 – J.L. Baird invents the television (30 line vertical, black and red scan).

# Developmental History

- 1967 - GE introduces first full colour real time flight simulator for NASA
- 1974 - Intel develop the 8080 processor.

SP3 was the first of the NOVOVIEWs certified by the FAA for Phase III training.

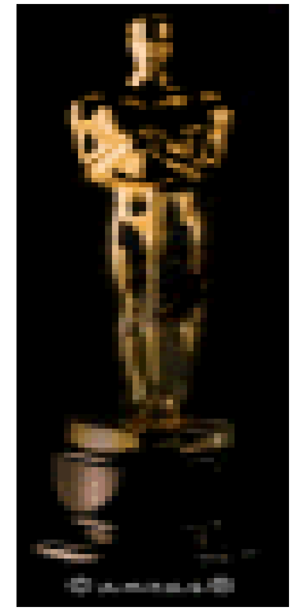


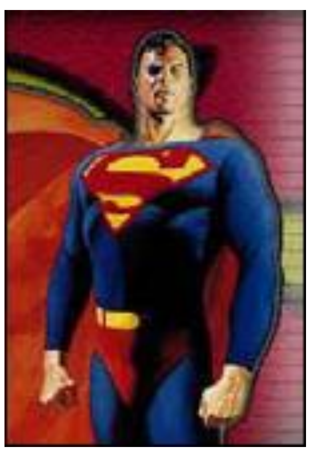
- 1975
  - Mandelbrot plots fractals
  - Bill Gates starts Microsoft

- 1976 - Steve Jobs and Steve Wozniak start Apple.

# Developmental History

- 1977
  - Academy of Motion Pictures Art and Sciences introduces Visual Effects category for Oscars.
  - Star Wars wins oscar for special effects.

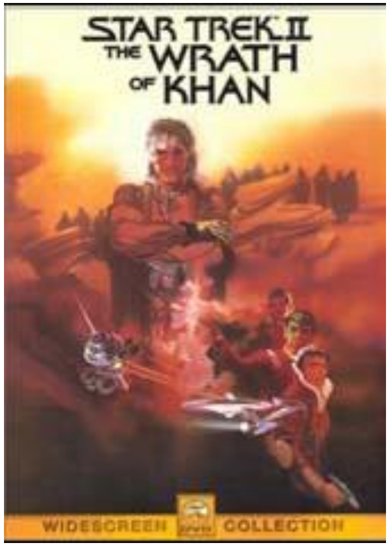




- 1978 - Superman wins oscar for special effects.

# Developmental History

- 1981
  - IBM introduces the first IBM PC (16 bit 8088 chip)
  - Raiders of the Lost Ark wins an oscar for visual effects.


- 1982 - The Genesis Effect (ILM) for Startrek II is the first all computer animated visual effects shot for film.

# Developmental History

- 1983 - First Coke Polar Bears Commercial
- 1984 - PIXAR Opens


- 1985 -The Last Starfighter is the first live action feature film with realistic computer animation of highly detailed models.

# Developmental History


- 1995 - Toy Story becomes the first fully 3D computer animation feature film.


- 1996 - Independence Day wins oscar for visual effects.


- 1997
- Titanic wins oscar for visual effects.
- PIXAR wins oscar for best short film: Geri's Game.

# Developmental History

- 1999
  - The Matrix
  - Disney's Tarzan
  - Star Wars: The Phantom Menace

- 2000
  - Sony Playstation II
  - Walking with Dinosaurs
  - Disney's Shrek

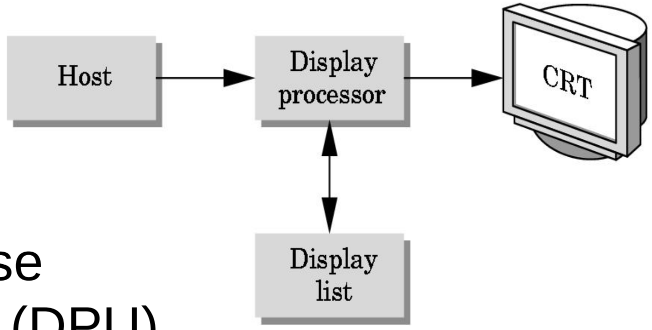
# Developmental History: 1950-1960

- Computer graphics goes back to the earliest days of computing
  - Strip charts
  - Pen plotters(e.g. HP 7470)
  - Simple displays using A/D converters to go from computer to calligraphic CRT

- Cost of refresh for CRT too high
  - Computers slow, expensive, unreliable

# Developmental History: 1960-1970

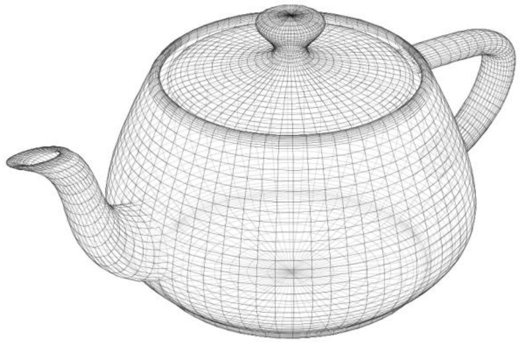
- Sketchpad: IvanSutherland’s PhD thesis at MIT
  - Recognized the potential of man-machine interaction
  - Loop:
    - Display something
    - User moves light pen
    - Computer generates new display
  - Sutherland also created many of the now common algorithms for computer graphics




- Display Processors:
  - Rather than have the host computer try to refresh display use a special purpose computer called a display processor unit (DPU)
  - Graphics stored in display list (display file) on display processor
  - Host compiles display list and sends to DPU

# Developmental History: 1960-1970

- Vector graphics:
  - are defined in terms of 2D points, which are connected by lines and curves to form polygons and other shapes
  - each of these points has a definite position on the x- and y-axis of the work plane and determines the direction of the path
  - each path may have various properties including values for stroke color, shape, curve, thickness, and fill.



# Developmental History: 1960-1970


Wireframe


Skeletal model


Muscle model


Skin


Hair

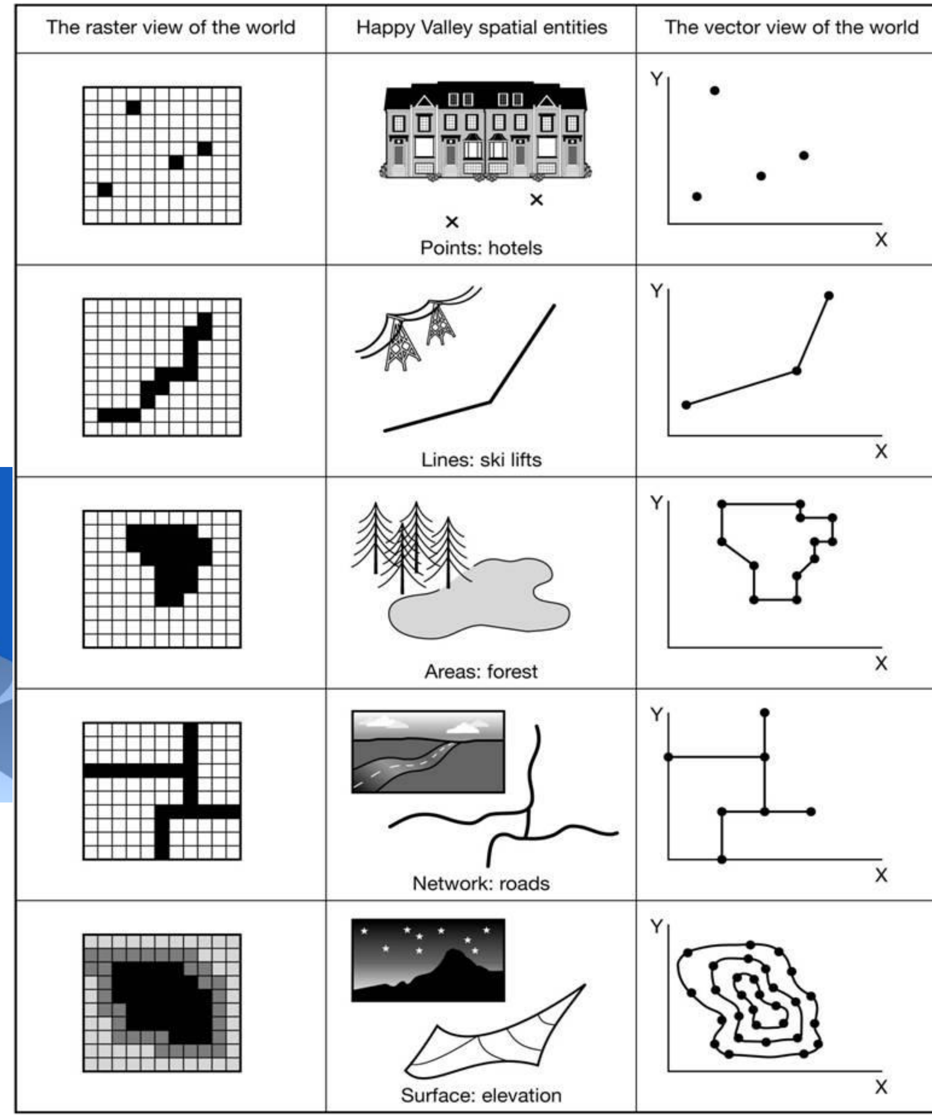

Render and Touch up

Vector graphics= geometrical model + rendering

# Developmental History: 1970-1980

- Raster Graphics:
  - Image produced as an array of picture elements (pixels) in the frame buffer
  - scan lines/area to filled polygons

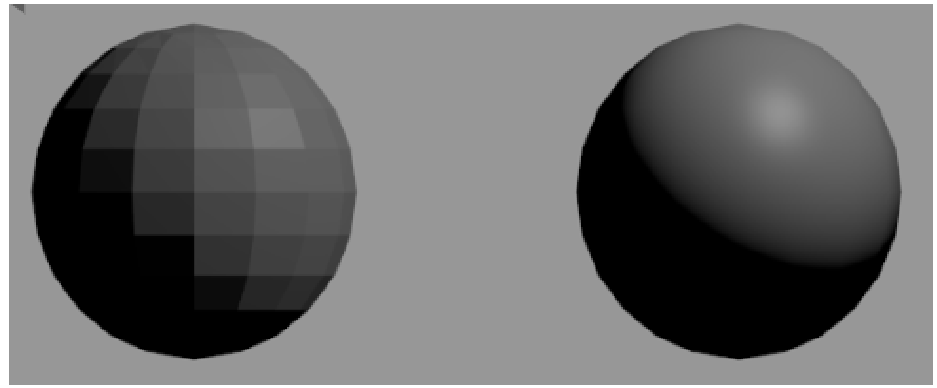
- Raster vs Vector:



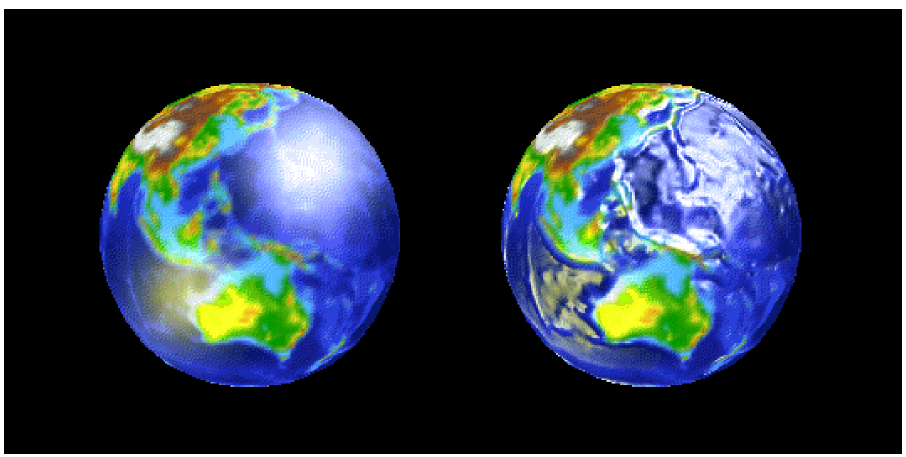
# Developmental History: 1980-1990

- Realism comes to computer graphics

**Shading ⇨**



flat smooth



environment bump

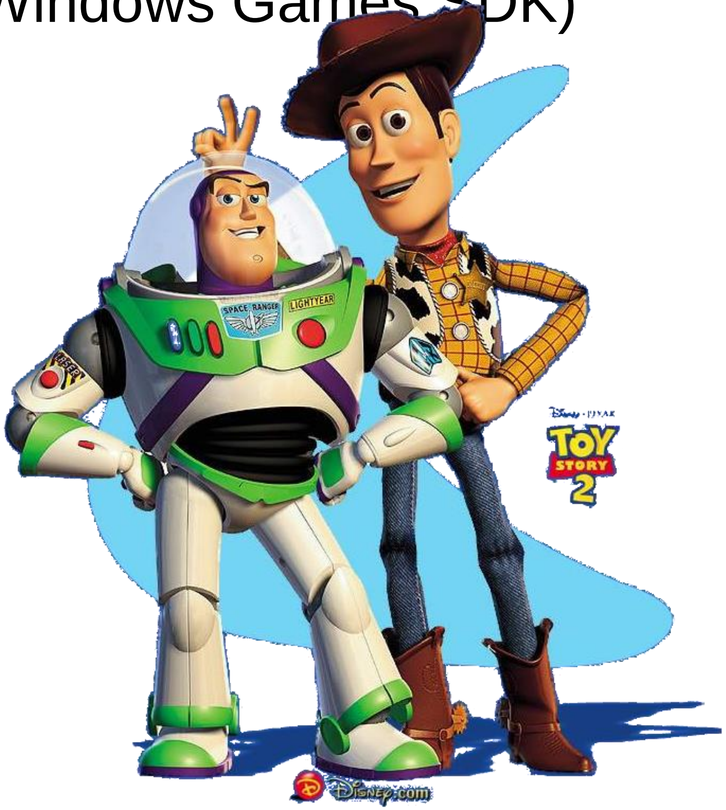
**⇦ Mapping**

# Developmental History: 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)

# Developmental History: 1990-2000

- Completely computer-generated feature-length movies (Toy Story) are successful
- OpenGL API
- DirectX (September 1995 as the Windows Games SDK)
- New hardware capabilities
  - Texture mapping
  - Blending
  - Accumulation, stencil buffers



# Developmental History: 2000-…

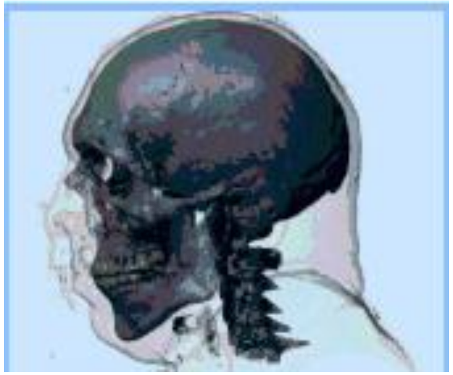
- Photorealism (real-time)
- Graphics cards for PCs dominate market
  - Nvidia, ATI
- Game boxes and game players determine direction of market
- Computer graphics routine in movie industry: Maya, Lightwave
- Programmable pipelines

# Applications Areas

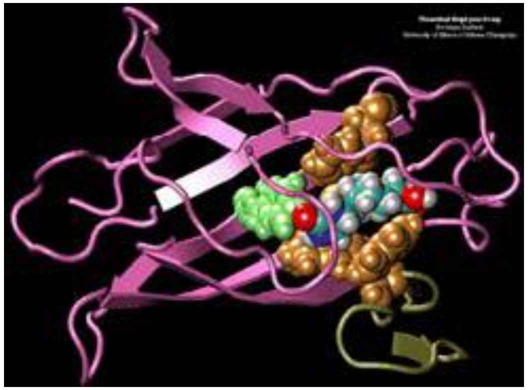
- Look at 5 areas
  - Hardware
  - Rendering
  - Interaction
  - Modeling
  - Scientific Visualization

Game/Film Industry

Computer Aided Design

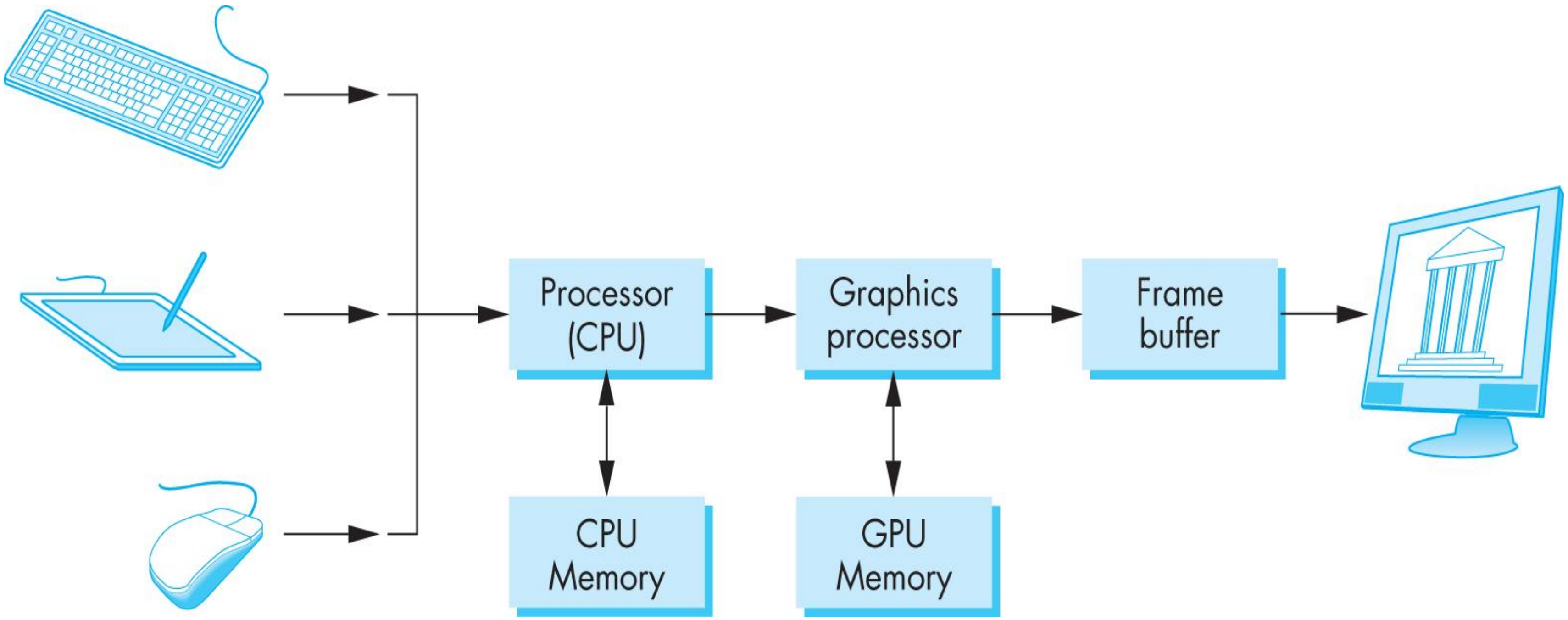


Medical Imaging



Scientific Visualization

# Basic Graphics System

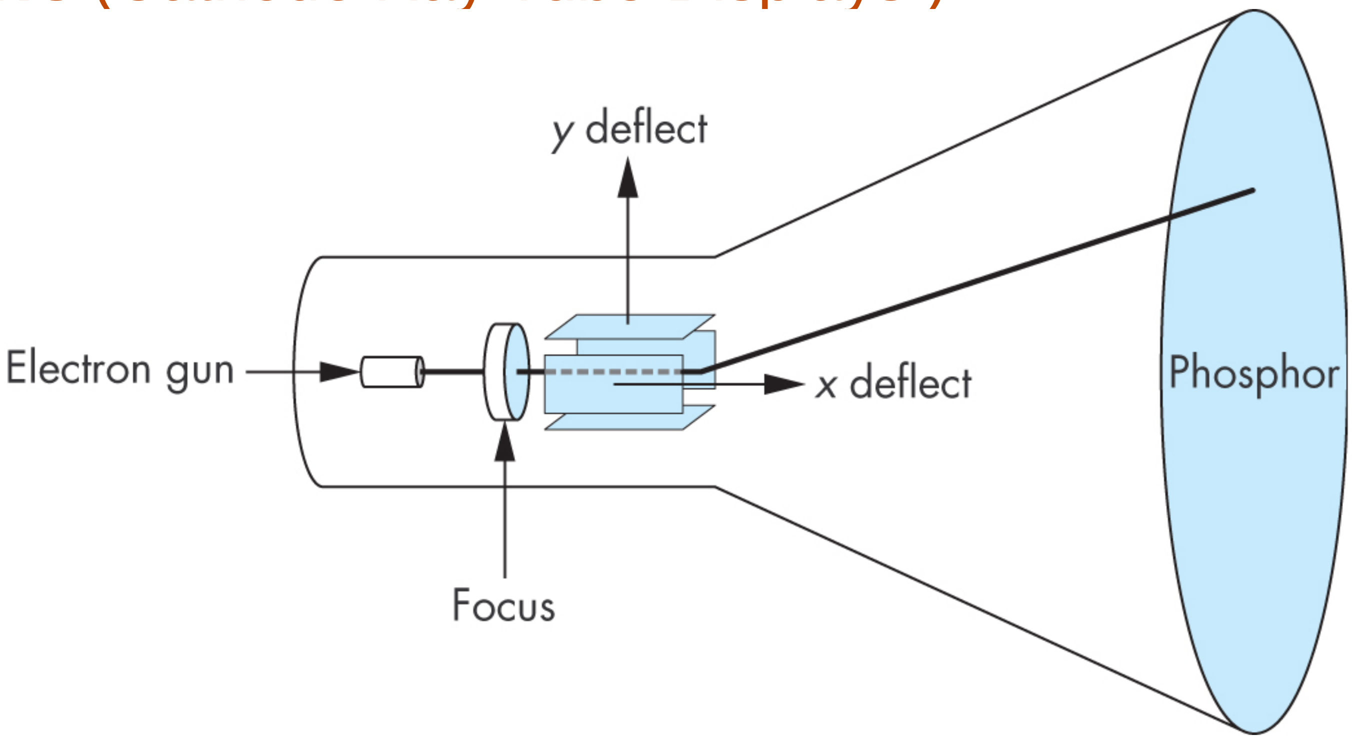



Input devices

Output device

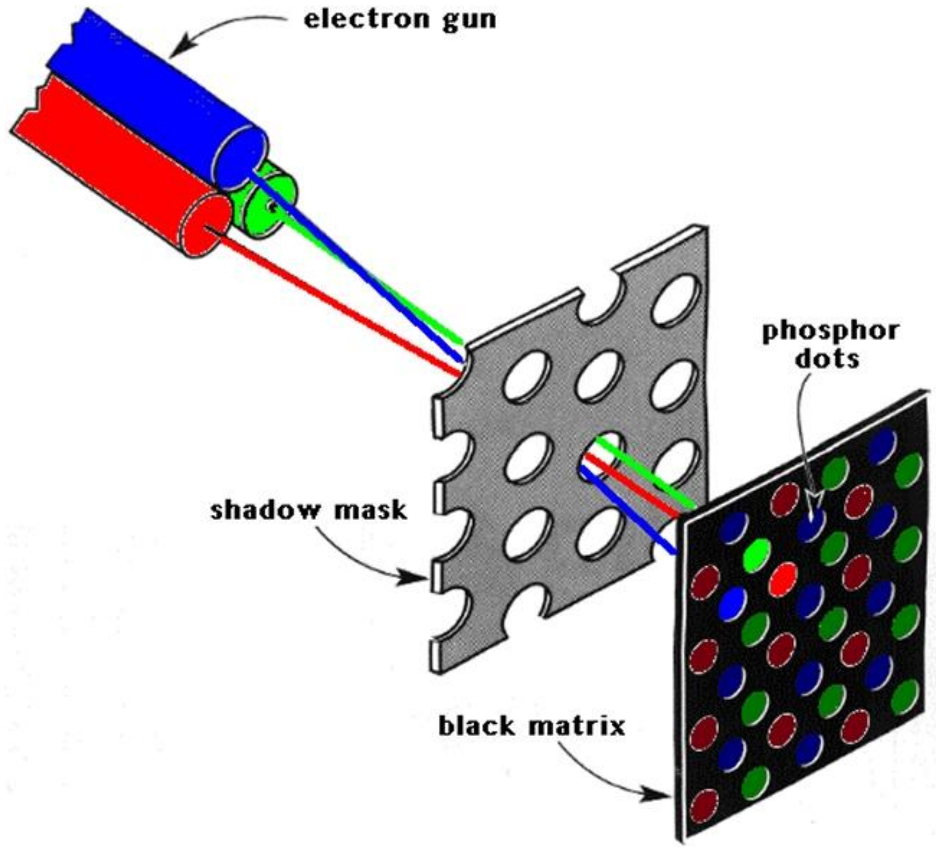
Image formed in frame buffer

**CRTs** (Cathode Ray Tube Displays )




Can be used either as a line-drawing device (calligraphic) or to display contents of frame buffer (raster mode)

## CRTs



# Basic Graphics System

## CRTs

- Resolution:
  - TV:  640x480x8b 1/4 MB
  - Laserprinter:
    - 300 dpi (8.5"x300)(11"x300) 1.05 MB
    - 2400 dpi (8.5"x2400)(11"x2400) ~64 MB
- Aspect Ratio
  - Frame aspect ratio (FAR) = horizontal/vertical size
- Refresh Rates
- Coordinate system

## CRTs

### Advantages:

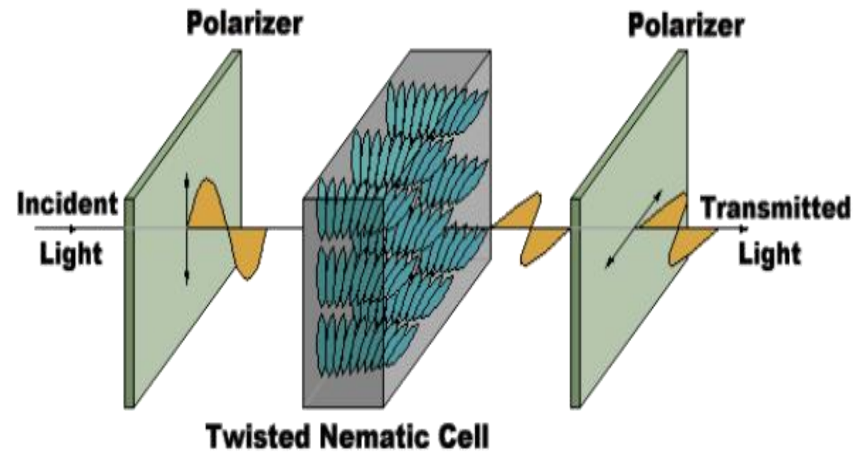
- High resolution possible
- Full color (large modulation depth of E-beam)
- Saturated and natural colors
- Inexpensive, matured technology
- Wide angle, high contrast and brightness

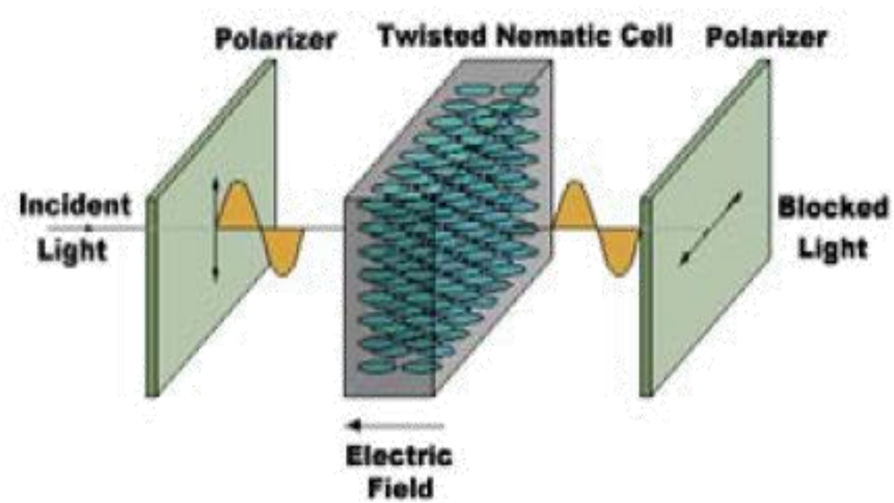
### Disadvantages:

- Large and heavy (typ.70x70cm, 15kg)
- High power consumption (typ.140W)
- Harmful DC and AC electric and magnetic fields
- Flickering at 50-80 Hz (no memory effect)
- Geometrical errors at edges

## **LCDs** (Liquid Crystal Displays)

- A transmissive technology
- Works by letting varying amounts of a fixed-intensity white backlight through an active filter
- Organnic crystals that lign themselves together
- When external force is applied they realign themselves
- This is used to change polarisation and filter lighttem



## LCDs

**Advantages:**

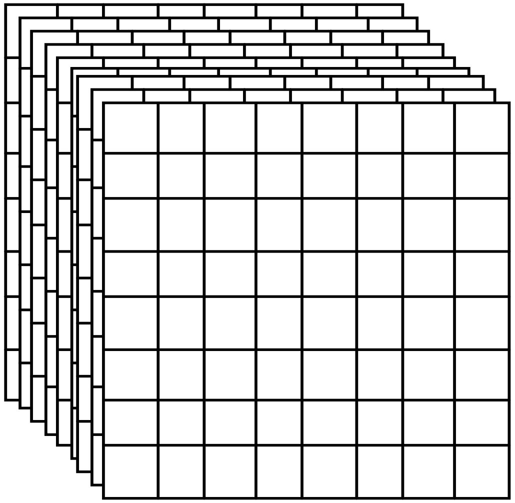
- Small footprint (approx 1/6 of CRT)
- Low power consumption (1/4 of CRT)
- Completely flat screen – no geometrical errors
- Crisp pictures - digital and uniform colors
- No electromagnetic emission
- Fully digital signal processing possible
- Large screens (>20 inch) on desktops

**Disadvantages:**

- High price (presently 3x CRT)
- Poor viewing angle (typ. +/- 50 degrees)
- Low contrast and luminance (typ.1:100)
- Low luminance (typ. 200 cd/m2)

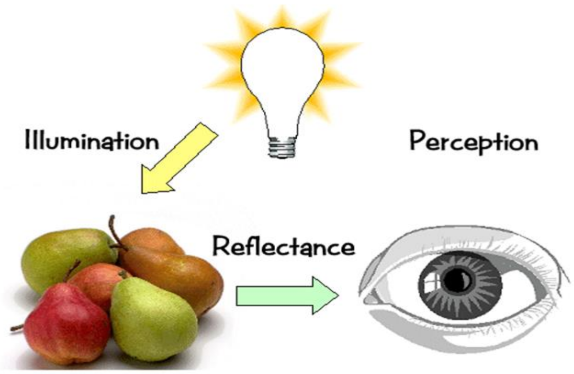
## **Frame Buffer** (Video RAM)

- Frame buffer
  - size,
  - x, y,
  - pixel depth.
- Resolution
  - Ex: 1024x1024 pixels.
- Bit Planes / Bit Depth
  - ? bit/pixel.
  - color resolution of video RAM.

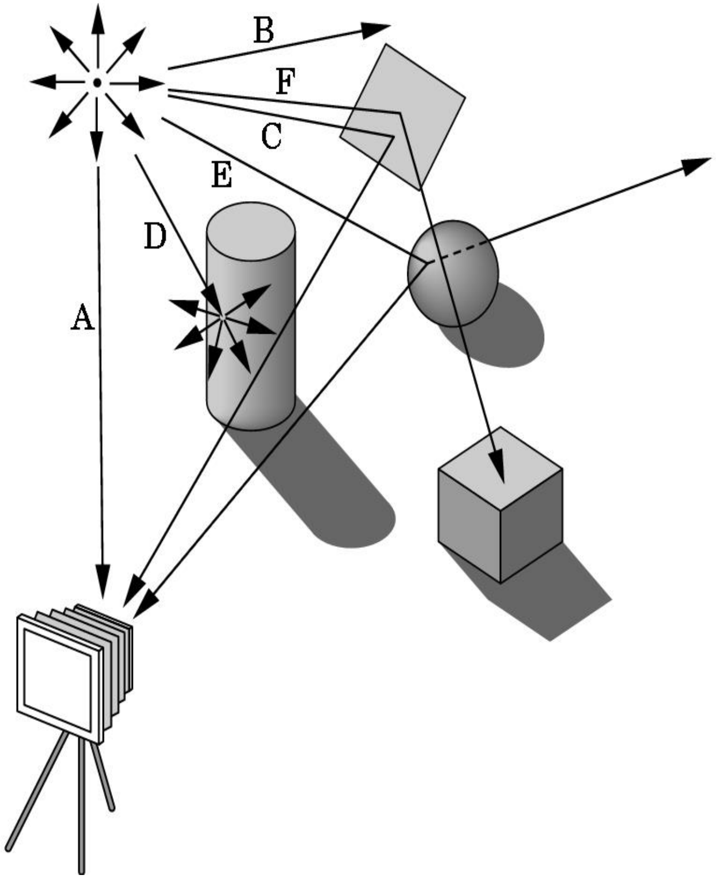


1 bit/pixel ⇨ Monochrome display
8 bits/pixel ⇨ 256 màu
24 bits/pixel ⇨ 16,777,216 màu

# Elements of Image Formation

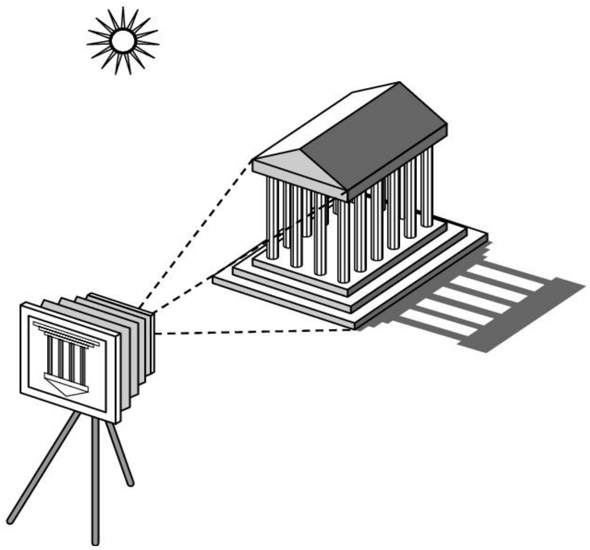


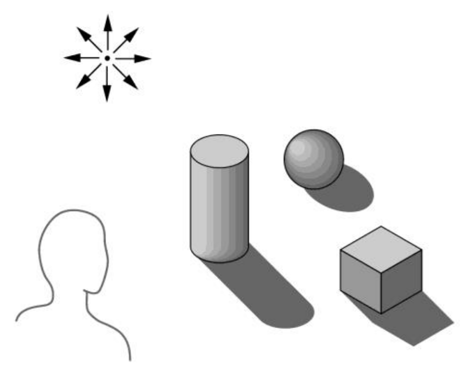

- Each light ray may have interactions with objects before being absorbed or going to infinity
- One way to form an image is to follow light rays from a point source, finding which rays enter the lens of the camera.



# Elements of Image Formation

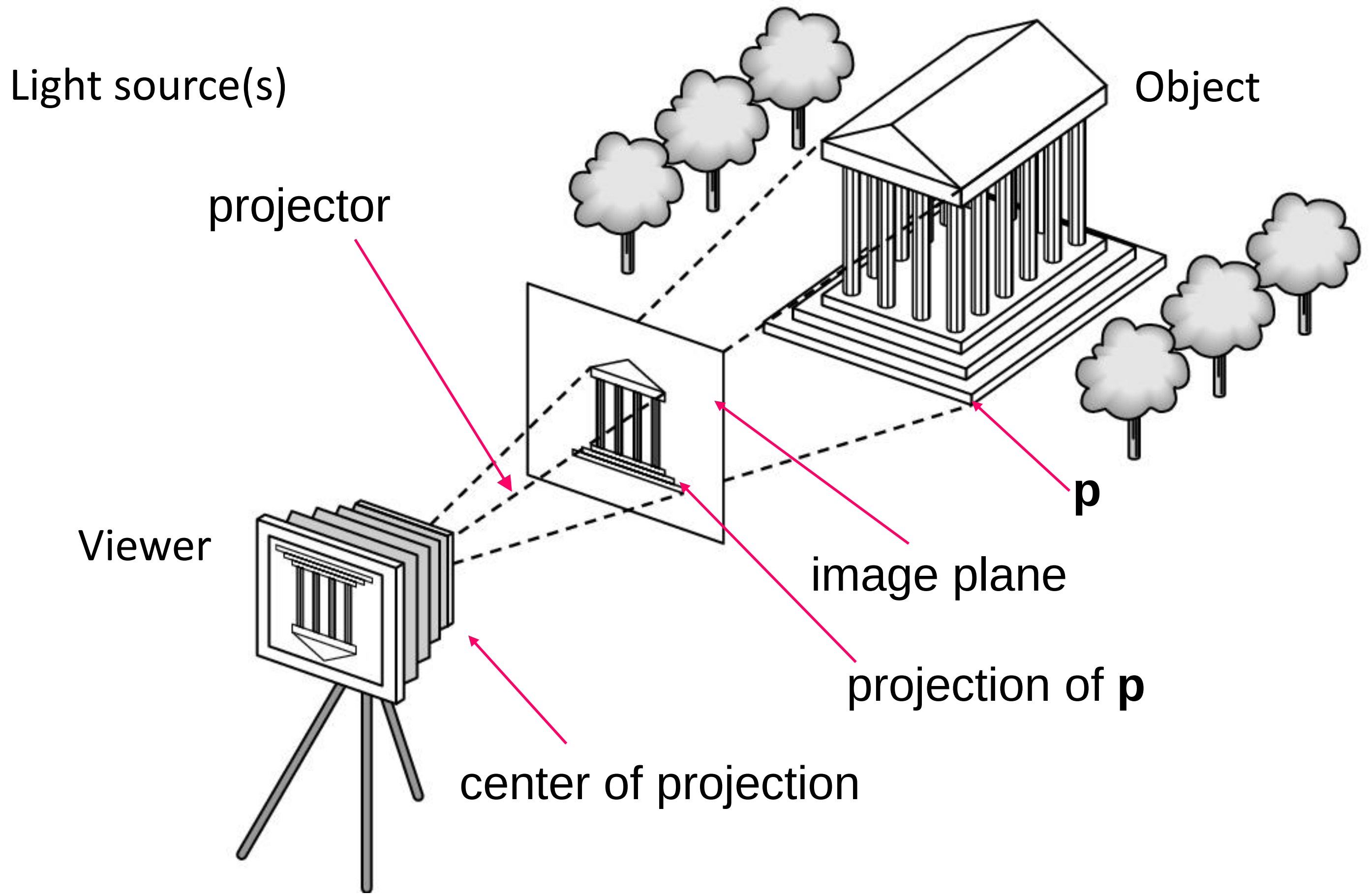
- In computer, 2D images are formed from a process analogous to how images are formed by physical imaging systems
- Elements of Image Formation:
  - Objects
  - Viewer
  - Light source(s)
    - Light: Global  >< Local
    - Cannot compute color or shade of each object independently
    - Some objects are blocked from light
    - Light can reflect from object to object
    - Some objects might be translucent.





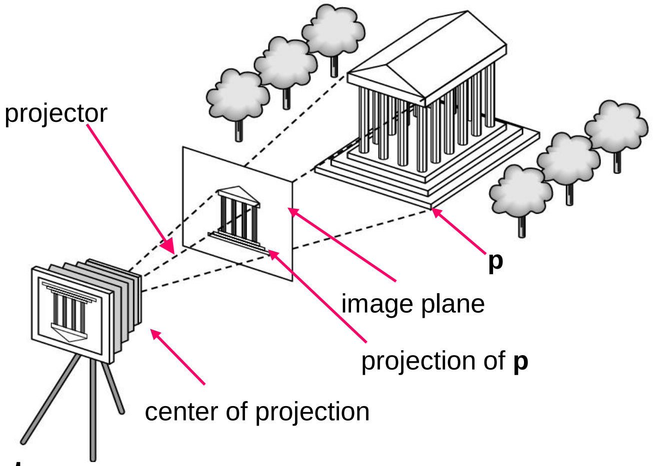
# Elements of Image Formation

## Synthetic Camera Model



# Elements of Image Formation

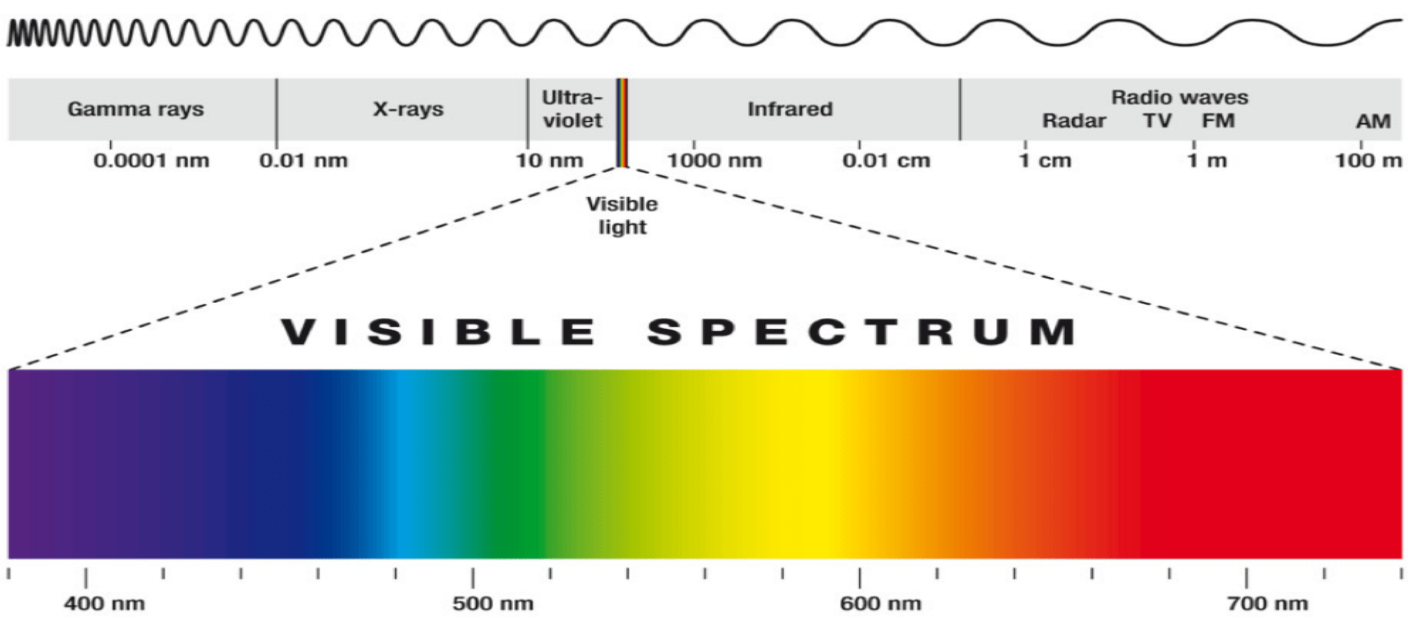
## Synthetic Camera Model




- Advantages
  - Separation of objects, viewer, light sources
  - 2D graphics is a special case of 3D graphics
  - Leads to simple software API
    - Specify objects, lights, camera, attributes
    - Let implementation determine image
  - Leads to fast hardware implementation

## Colors

- Color: a narrow frequency band within the electromagnetic spectrum, with wavelengths in the range of about 350-750 nm
- In visible band, each frequency corresponds to a distinct color
- High-frequency (short wavelength) appear as Violet, Low-frequency (long wavelength) as Red.

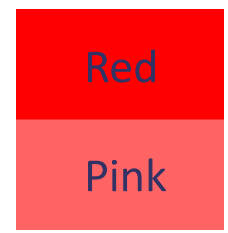


## Color Terminology

- **Hue** (color) is a dominated wavelength or pure color with no black or white added (blue, green, red, etc.). The same colors may increase the intensity, but will not change the hue.

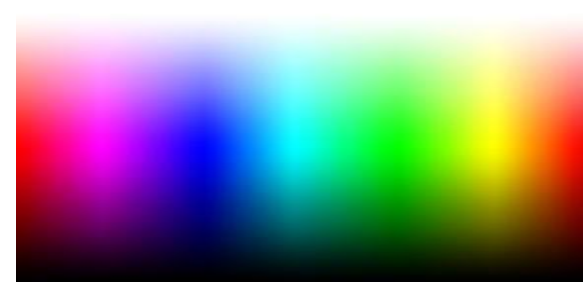
- **Saturation** (purity) refers to how strong or weak a color is, depends on the amount of white/black which is added to a color.

  *e.g*: Red and Pink have the same hue,
  but a different saturation





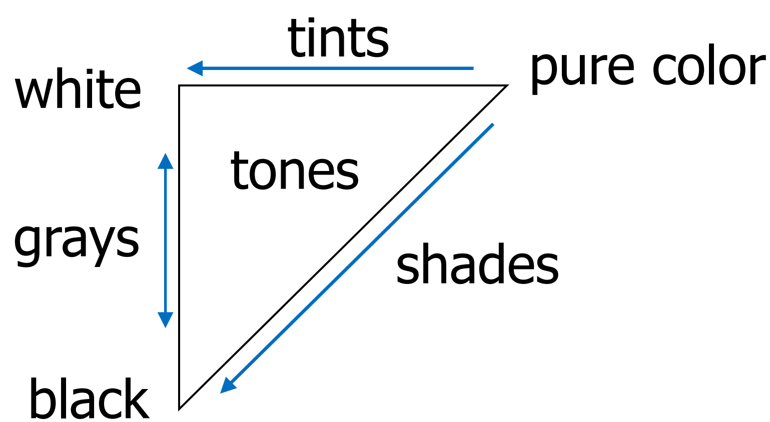
- **Lightness** is luminance (reflecting objects)
- **Brightness** is luminance
  (self-luminous objects, *e.g:* Sun, CRT)
- **Value** (Intensity, Lightness, Brightness) refers to how light or dark a color is (light having a high value).



## Color Terminology

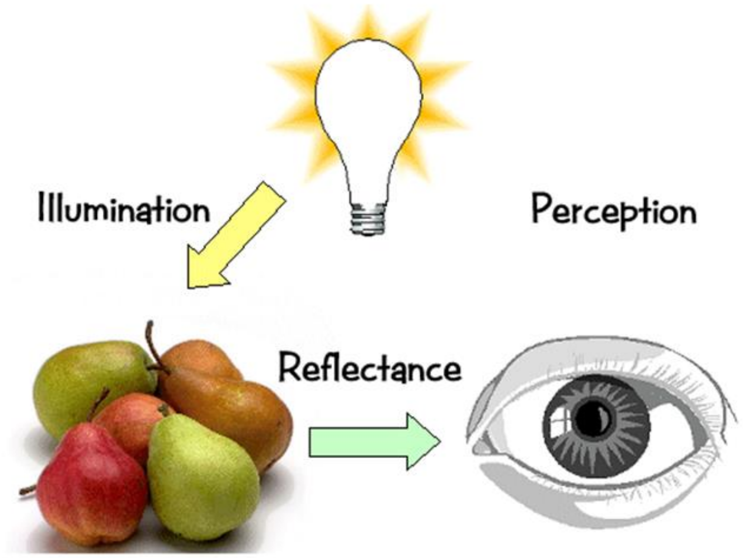
- **Tint** is created by adding white to a hue, making it lighter than the original color ⇨ Saturation reduced
- **Shade** is created by adding black to a hue, making it darker than the original color ⇨ Lightness reduced
- **Tone** is created by adding both white and black to a hue, making it darker/lighter than the original color.

- Gray = Black + White
- Tint, Shade, Tone
  ⇨ create different colors of the same hue.



## Colors of an object

- Light source emits “white light” (all frequencies of light)
- Object reflects/absorbs some frequencies
- Colors of an object = combination of frequencies reflected



## Luminance and Color Images

- Luminance Image
  - Monochromatic
  - Values are gray levels
  - Analogous to working with black and white film/television
- Color Image
  - Has perceptional attributes of Hue, Saturation & Lightness

Do we have to match every frequency in visible spectrum?
⇨ **No**! - Graphic packages provide color palettes to users
(often employ two or more color models)

# Color Models

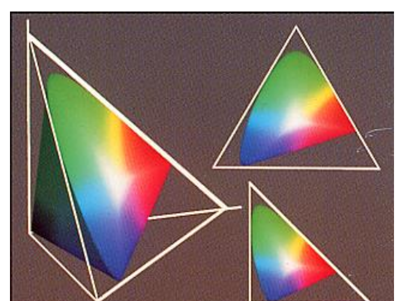
- **Color model**: an orderly system for creating a whole range of colors from a small set of primary colors.
- **CIE color model:** the most common color space were created by the International Commission on Illumination in 1931, known as the Commission Internationale de l'Elcairage (CIE).
  - three primary colors (saturated): X, Y, and Z
  - any color (color gamut): C = AX + BY + CZ,
  - normalized: $x = A/(A+B+C)$ ; $y = B/(A+B+C)$; $z = 1-x-y$

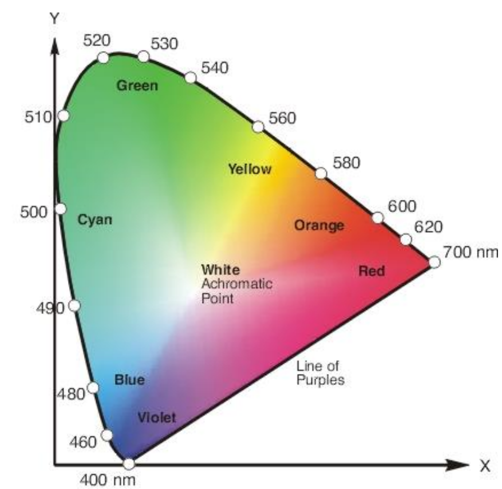
⇨**c** = xX + yY + zZ,

total light intensity: $x + y + z = 1$

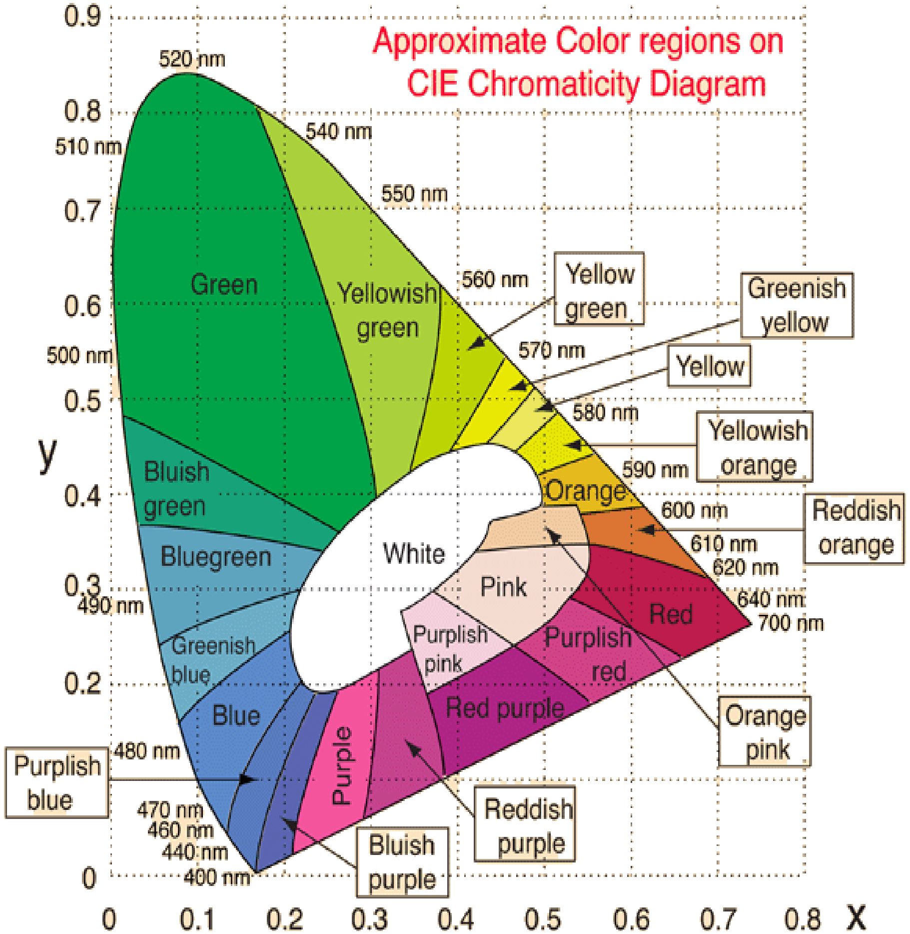
⇨**c** lies in the 3D plane:

$$x + y + z = 1$$



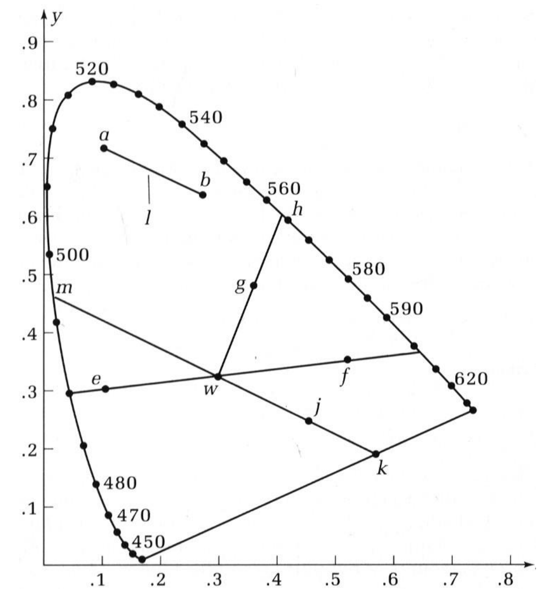


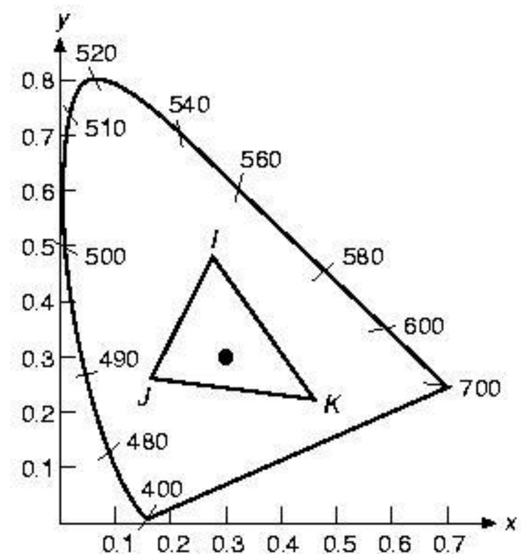
- **CIE chromaticity diagram**:
  - Plotting **c**($\lambda$)=(x($\lambda$), y($\lambda$)) by viewing the 3D curve in an orthographic projection, looking along the z-axis
  - Hue: inscribing a line from White through the color to the edge of the diagram, Hue is the wavelength of the color at the intersection of the edge and the line.
  - Saturation: the ratio of the distance of the color from White on the above line and the length of the whole line.



# Color Models

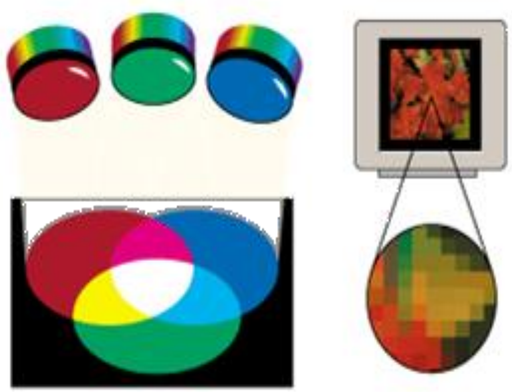
- **CIE chromaticity diagram**:
  - Any two colors on a line passing through White and added up to be white are *complementary colors*.
    - e.g: *e* and *f*
    - Red⇔Cyan; Green⇔Magenta; Blue⇔Yellow
  - Any color within a triangle can be generated by the three vertices of the triangle, called the *color gamut*.
    - a point inside ΔIJK is a convex combination of 3 points I, J, K

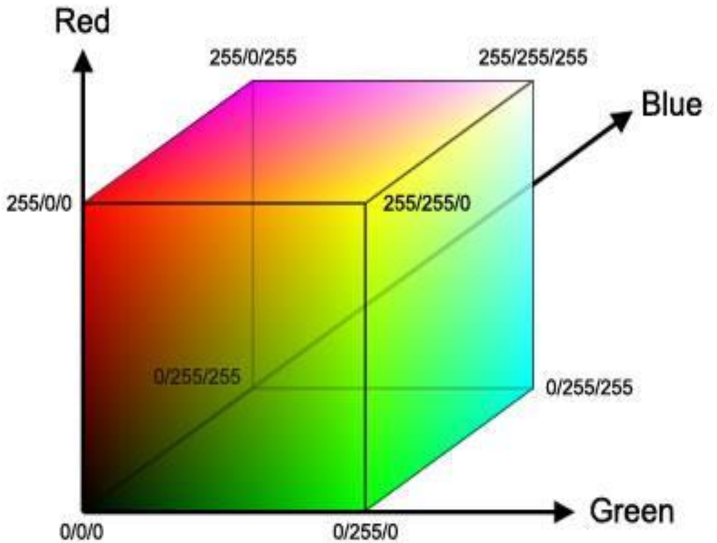


# Color Models

- Color gamut is a subset of all visible chromaticities, so color model does not contain all visible colors
- In the 3D color coordinate system, a subset can contain all colors within a gamut
- Example: RGB color model
  - 3D Cartesian coordinate system
  - Unit cube subset
  - Use CIE XYZ space to convert to

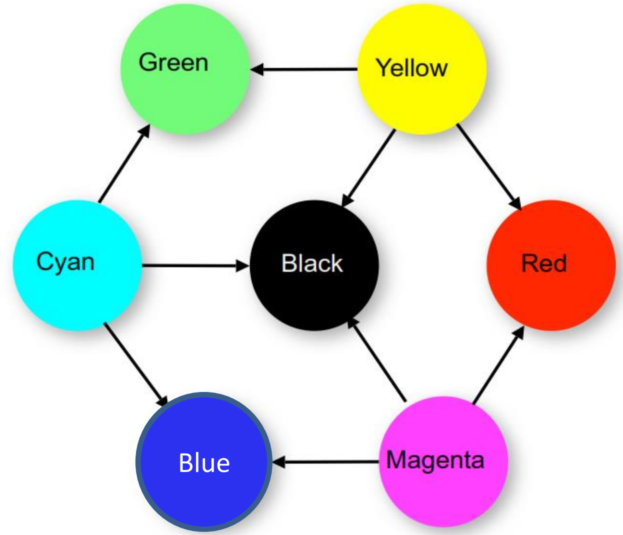


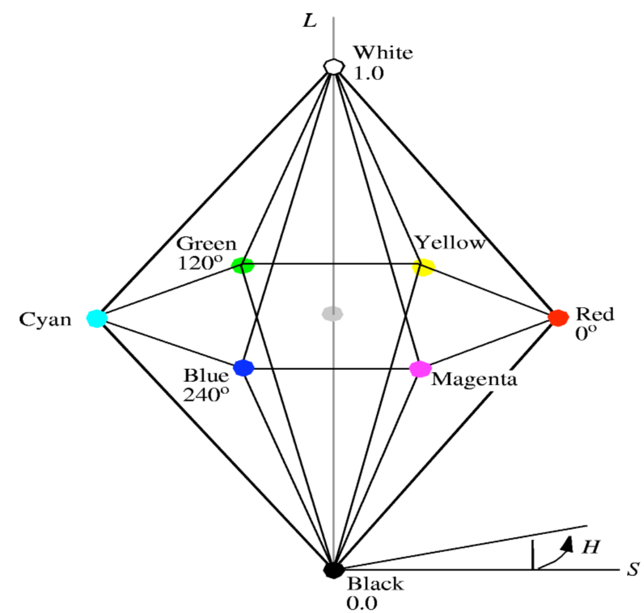


# Color Models

There are two types:

- **Hardware-oriented models**:
  not intuitive, do not relate to concepts of Hue, Saturation, Brightness
  - RGB ⇨for color monitors
  - CMY (cyan, magenta, yellow),
    CMYK (cyan, magenta, yellow, black)
    ⇨ for color printing
- **User-oriented models:**
  - HSV (hue, saturation, value),
    also called HSB (B-brightness)
  - HLS (hue, lightness, saturation)

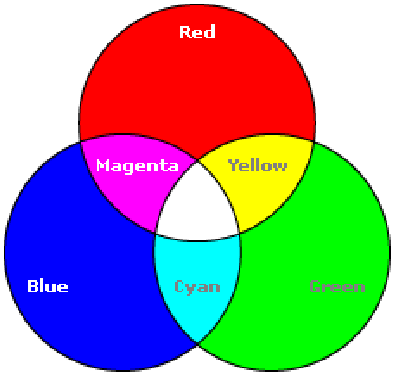


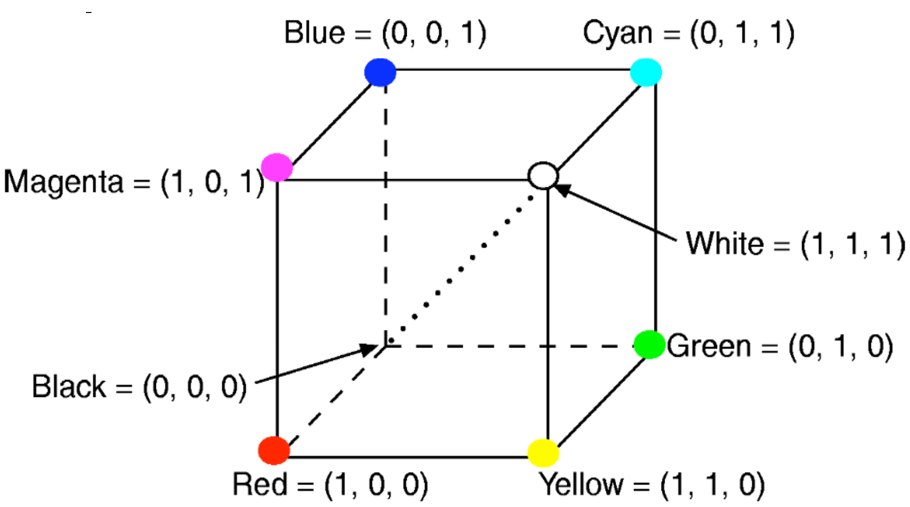



# Color Models

## The RGB Color Model

- RGB (Red-Green-Blue): an additive color model for computer displays uses light to display color.
- Gamut: individual contributions of each primary color added together. Gray levels on main diagonal.
  - $C = rR + gG + bB$, where $r, g, b \in [0, 1]$
  - Grays = (x, x, x), where x $\in$ (0, 1)
- Hue is defined by the one or t
- Saturation can be controlled by varying values of R, G, B
- Luminance can be controlled by varying magnitudes while keeping ratios constant



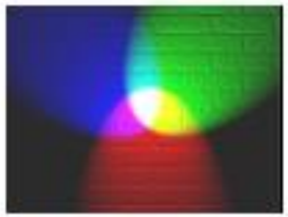
## The RGB Color Model

- Conversion from one RGB gamut to another: convert one to XYZ, then convert from XYZ to another
- Form of each transformation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

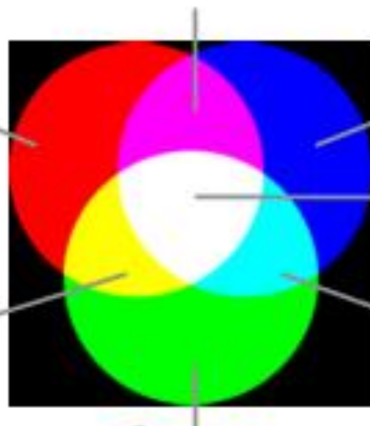
- Where Xr, Xg, and Xb are weights applied to monitor's RGB colors to find X, etc.

## Additive vs. Subtractive Color Systems

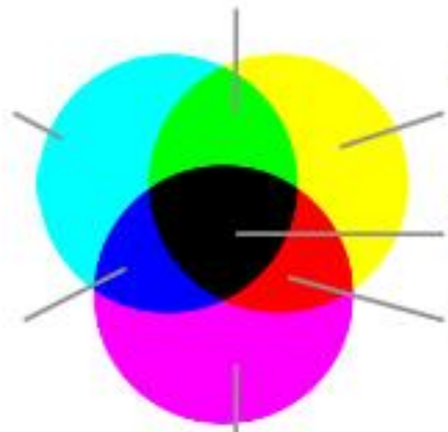


Mangenta

- Print systems use subtractive color system:

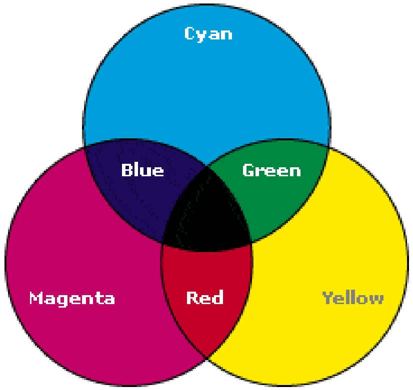



RGB



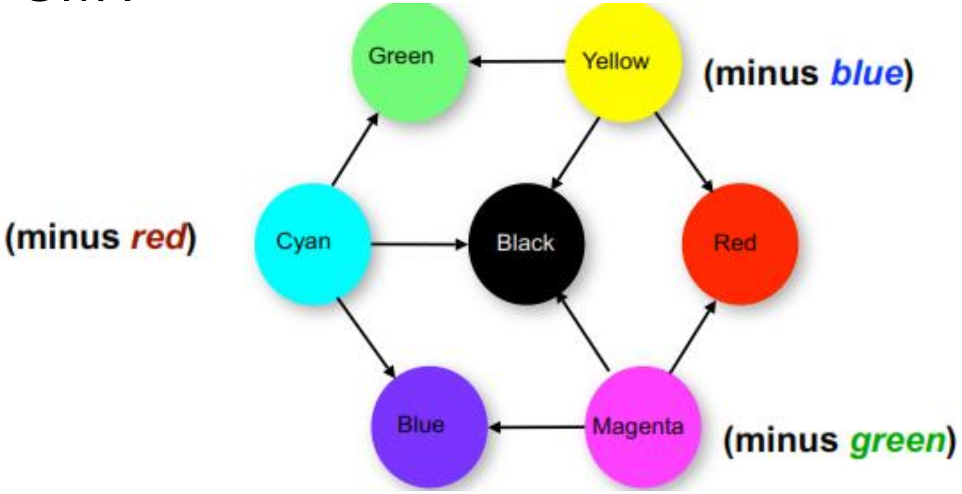

CMY

## The CMY Color Model



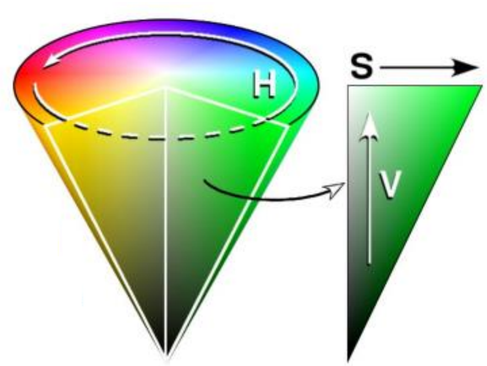

- CMY (Cyan-Magenta-Yellow): the subtractive color model used in light absorbing devices, color printing.
- Complements of RGB:
  - Color specified by what is subtracted from white light
  - C absorbs R, M absorbs G, and Y absorbs B
- Conversion from RGB to CMY

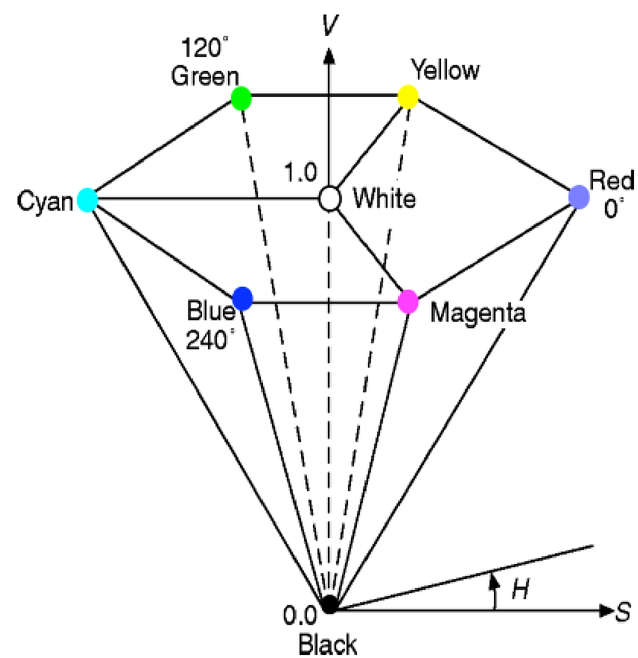
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



## The HSV Color Model

- HSV: Hue, Saturation, Value (Brightness)
- Hexcone subnet of Cylinder coordinate system
  - The V = 1 plane (hexagon) is obtained from the color cube in isometric projection.
  - Gamut = (h, s, v), where h ∈ [0, 360) and s, v ∈ [0, 1]
    - hue: angle round the hexagon
    - saturation: distance from the center
    - value: axis through the center



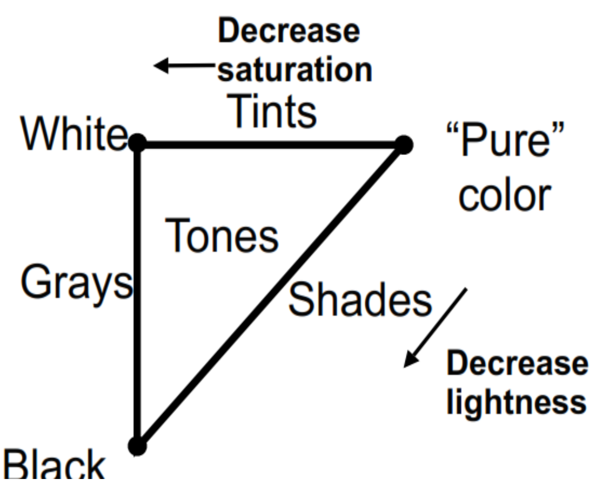



## The HSV Color Model

- Human eyes can distinguish: 128 hues, 130 saturations/tints, 23 shades of yellow colors, 16 of blue colors

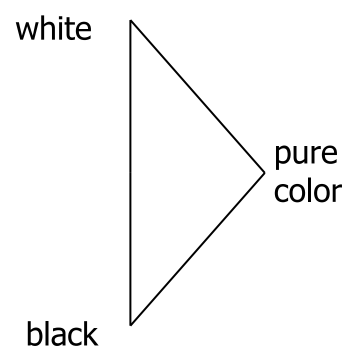
  ⇨ 128 x 130 x 23 = 82720 colors

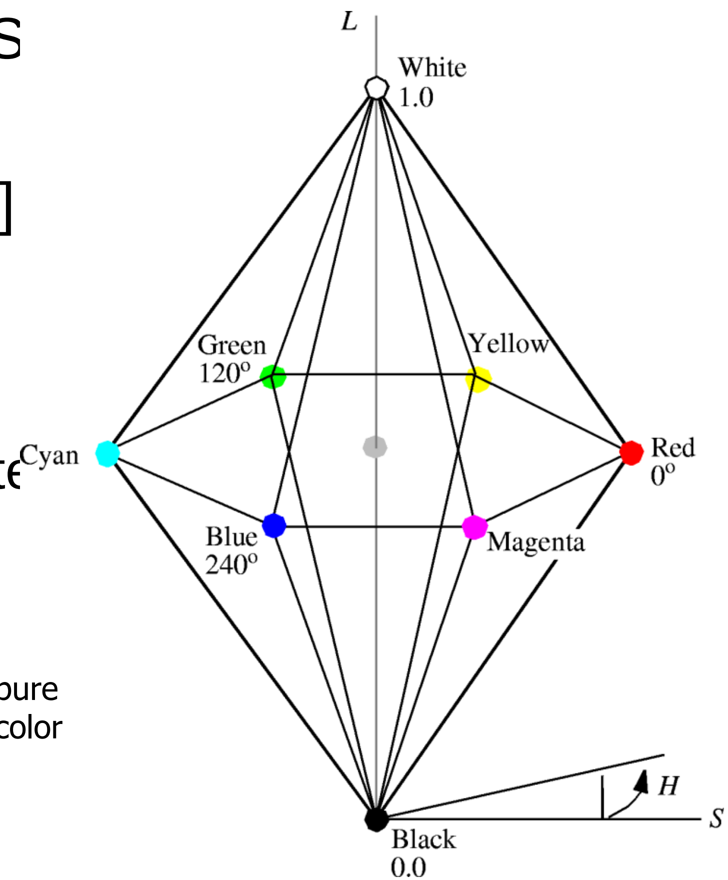
- Has intuitive appeal of the artist's tint, shade, and tone model
  - Pure pigments are (x,1,1);
    e.g: pure red ⇔ H = 0, S = 1, V = 1;
  - tints: adding white pigment
    ⇔ decreasing S at constant V
  - shades: adding black pigment
    ⇔ decreasing V at constant S
  - tones: decreasing S and V



## The HLS Color Model

- HLS: Hue, Lightness, and Saturation
- Double-hexcone subnet of Cylinder coordinate system
  - Base is from the hexagon as in HS
  - Gamut = (h, l, s),
    where h ∈ [0, 360) and l, s ∈ [0, 1]
    - hue: angle round the base
    - lightness: axis through the center
    - saturation: distance from the cente



# Overview of Computer Graphics

# Thank You…!