Image and Color

Introduction to Computer Graphics

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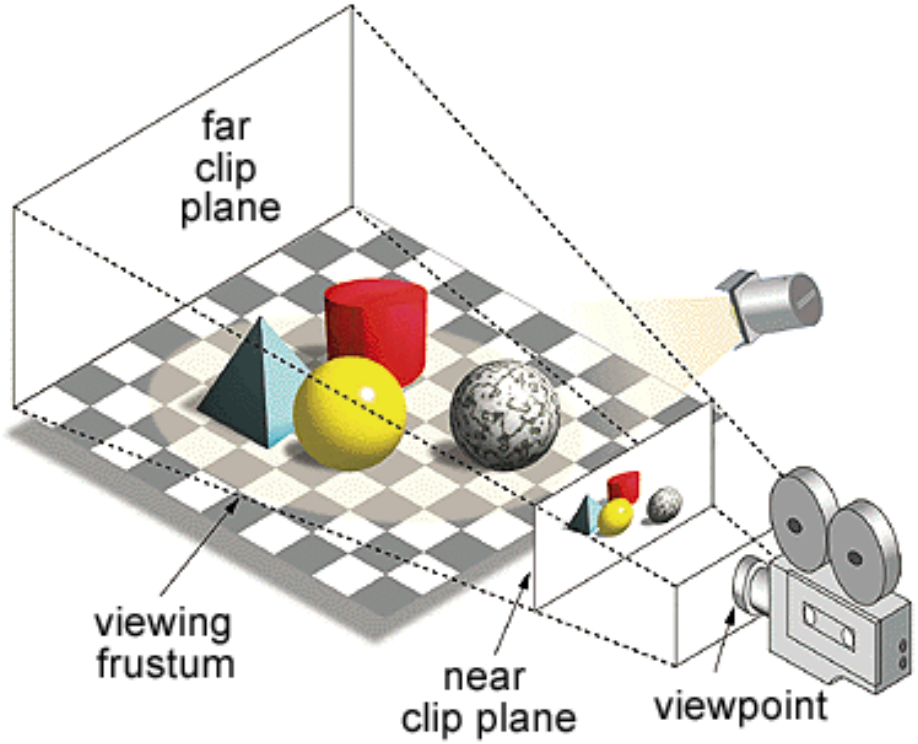
Recap.

- In computer graphics, we generate an **image** from a **virtual 3D world**
  - We are going to introduce the representation of an image



Image

Image Display

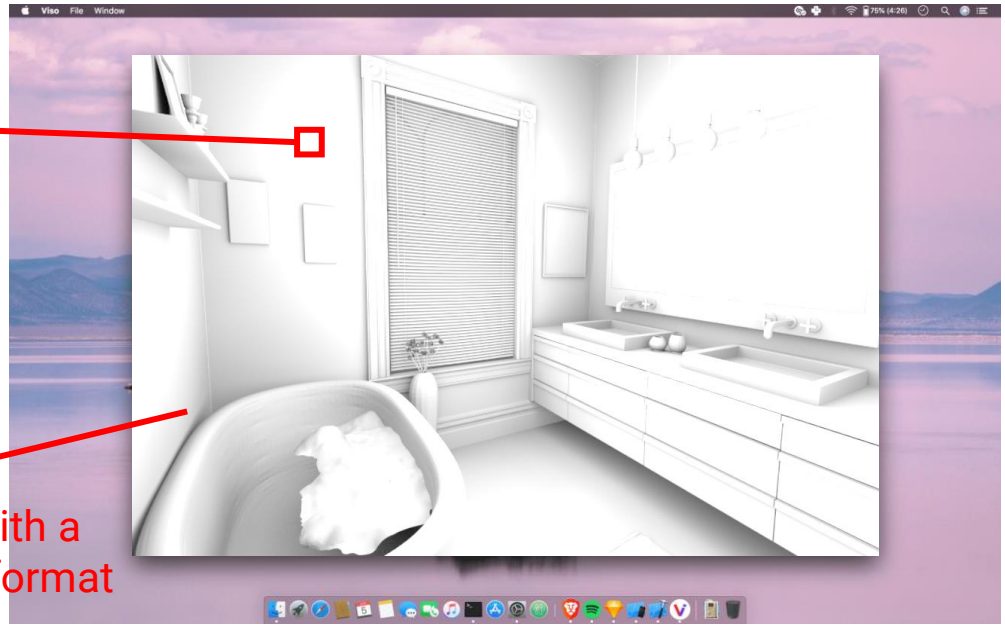
- Monitor display pictures as a **rectangular array of pixels** (small, usually square, dots of color)
  - Merge optically when viewed at a suitable distance to produce the impression of continuous tones

Programs set the **shade of grey or color (rendering)**

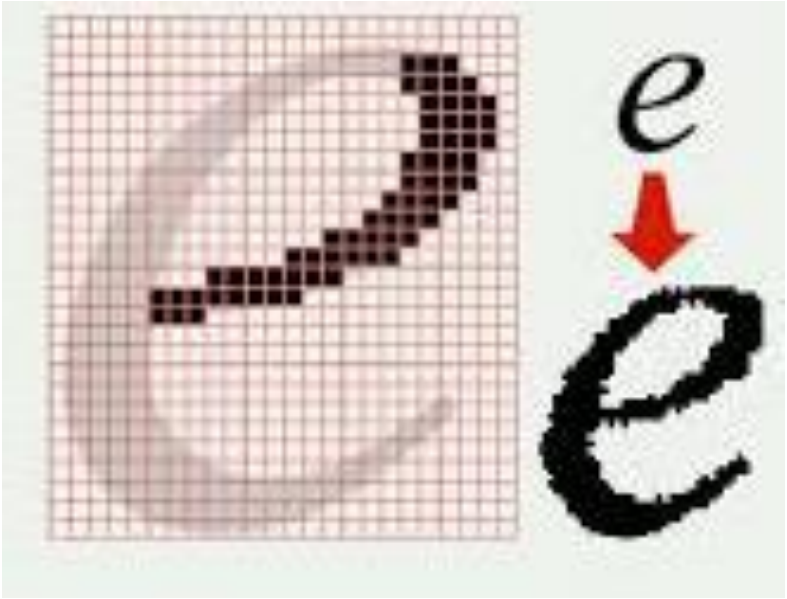
reconstruct pixel data from the format

Graphical Modeling

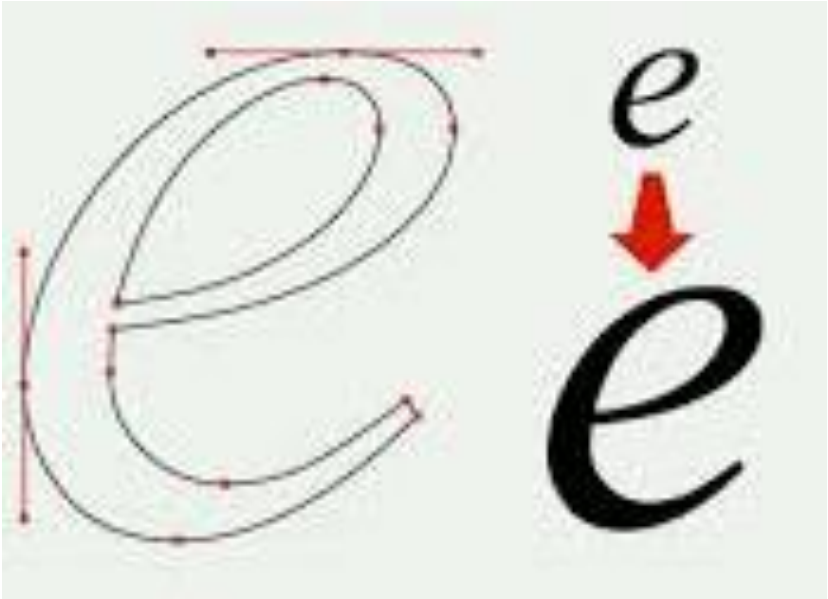
store with a specific format



Two Approaches for Graphical Modeling



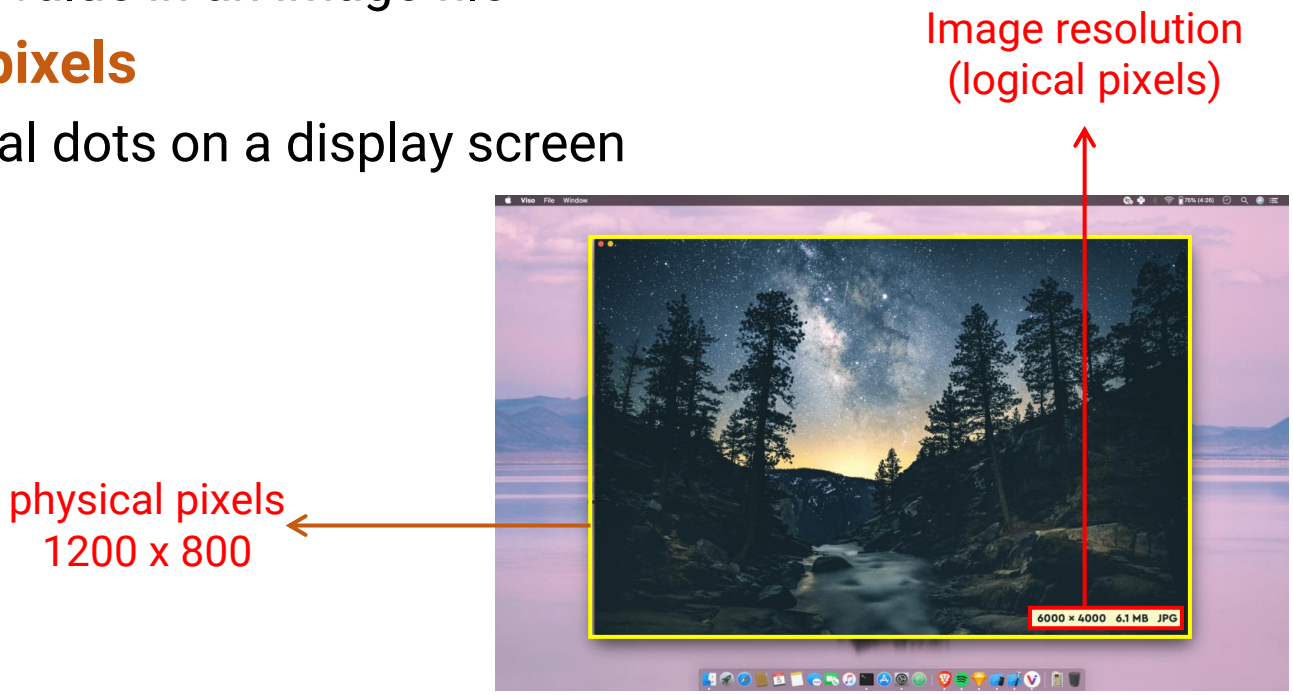
bitmapped images



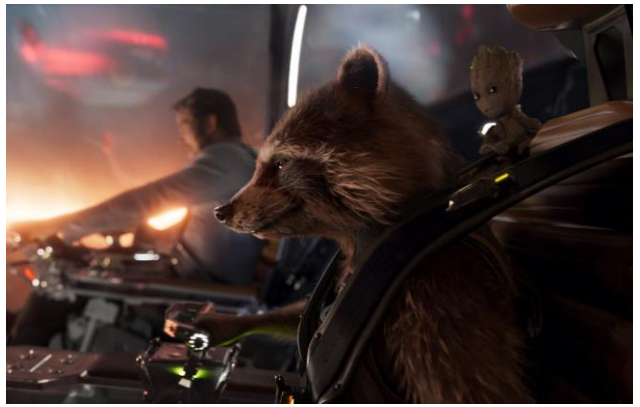
vector graphics

Bitmapped Images

- An image is modeled by an array of pixel values
- Distinction between
  - **Logical pixels**
    - Stored value in an image file
  - **Physical pixels**
    - Physical dots on a display screen

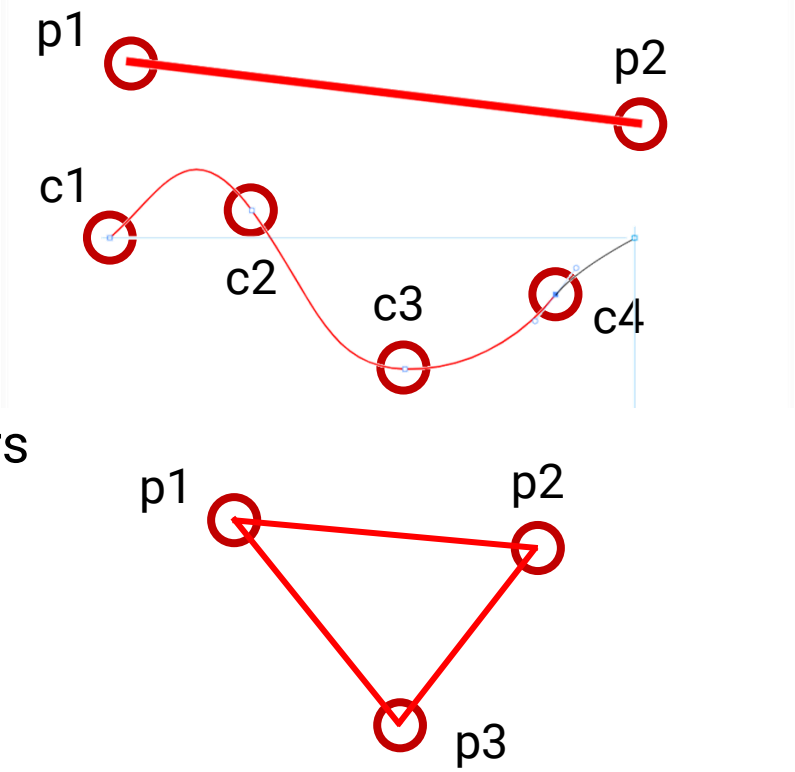


Bitmapped Images Examples

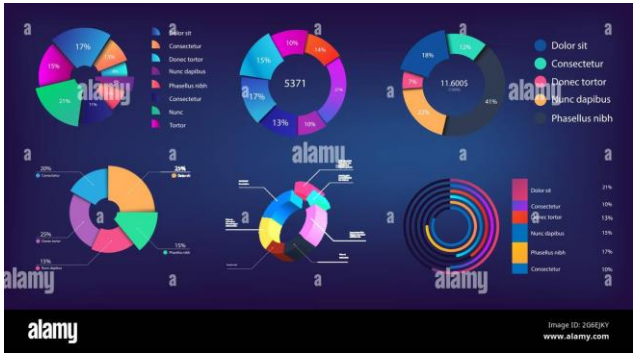


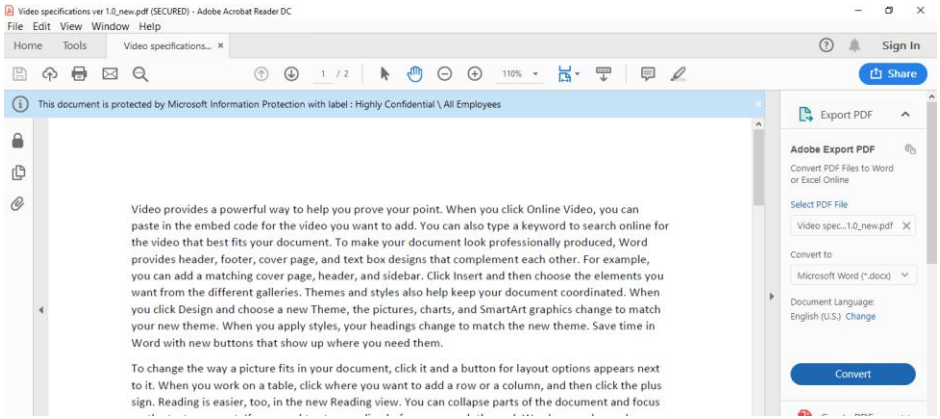
Vector Graphics

- An image is modelled by the mathematical description of a collection of individual objects making up the image
  - **Lines**
    - End points
  - **Curves**
    - Control points
  - **Shapes**
    - Shape-dependent parameters



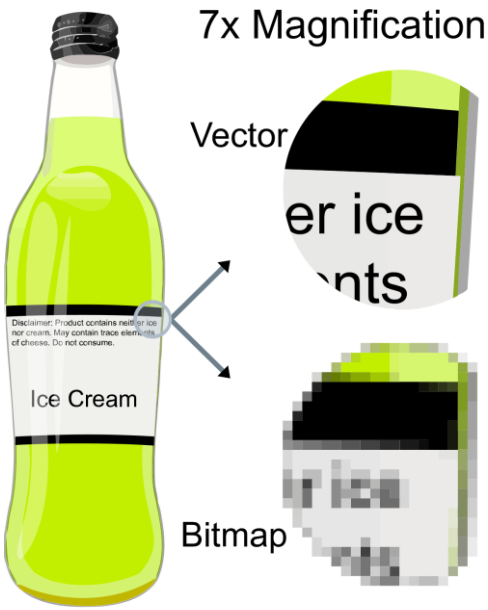
Vector Graphics Examples

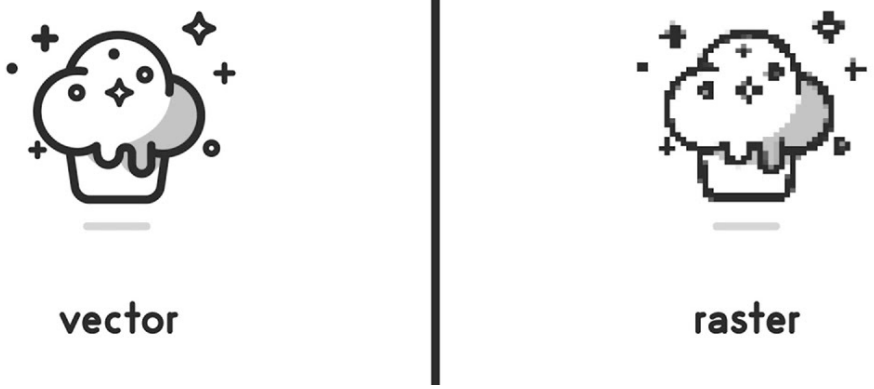




Bitmapped v.s. Vector Graphics

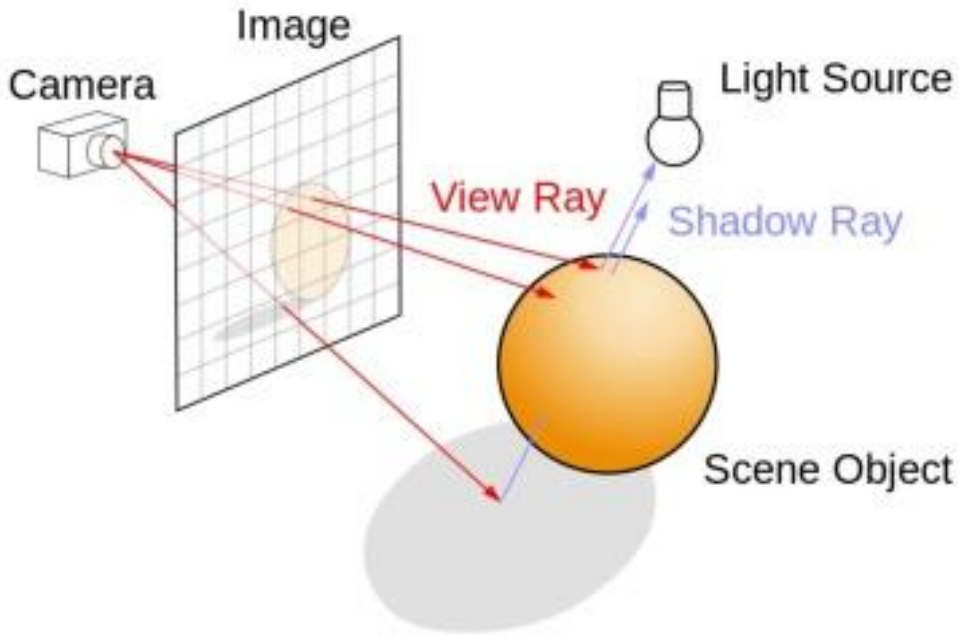
- Bitmapped images provide **better control of pixel values**, thus being more suitable for natural images
- Vector graphics are **resolution independent**, thus being more suitable for texts and icons





3D Graphics

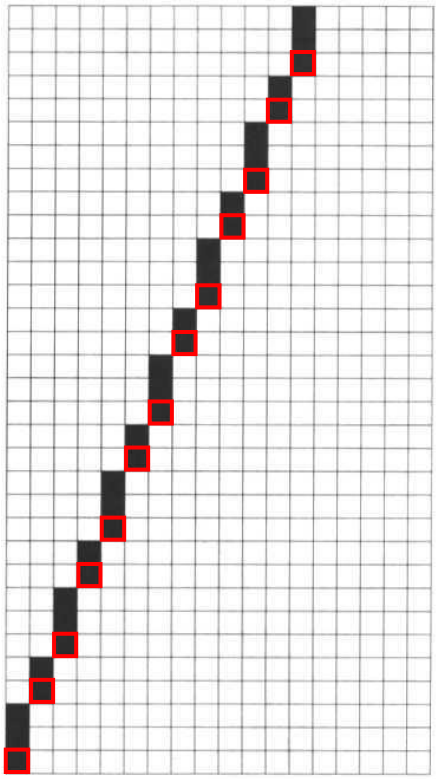
- A **combination** of vector and bitmapped graphics
- Shapes are defined in the virtual 3D space and projected (rasterized) to the 2D image plane



Rendering of Math

- When it becomes necessary to render a vector drawing, the **stored values** (e.g., endpoints of a line) are used in conjunction with the **general form** of the description of each class of object
  - Can be considered as **sampling**
- Example: y = 5x/2 + 1

  pass through (0, 1), (1, 4), (2, 6), (3, 9) …



- Jaggedness is inevitable!
  - Due to the use of a grid of discrete pixels

Anti-aliasing

- Anti-aliasing is a **practical** technique to reduce the jaggies
- Use intermediate grey values
  - In the frequency domain, it relates to reducing the frequency of the signal
- Coloring each pixel in a shade of grey whose **brightness is proportional to the area** of the intersection between the pixels and a "**one-pixel-wide**" line

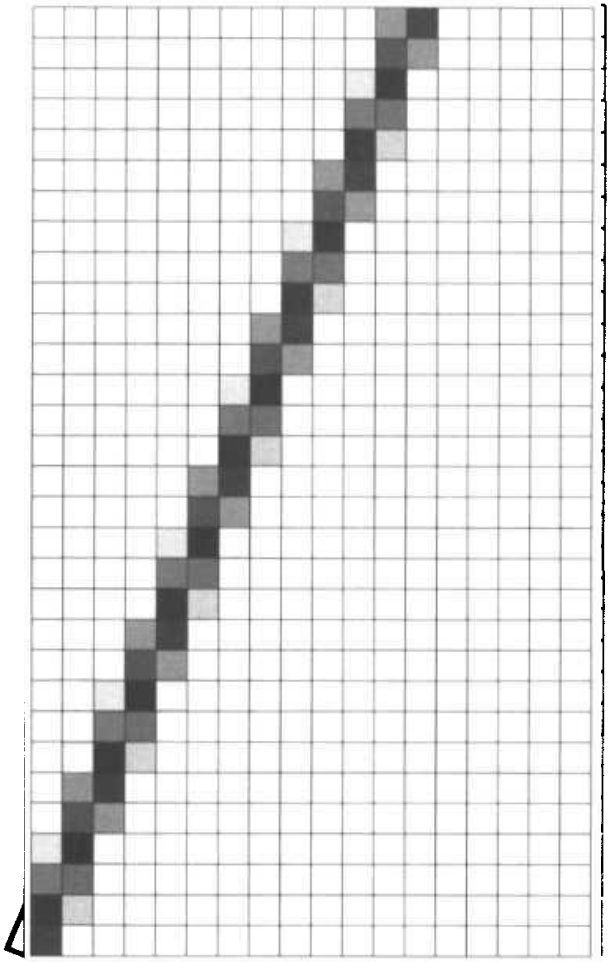
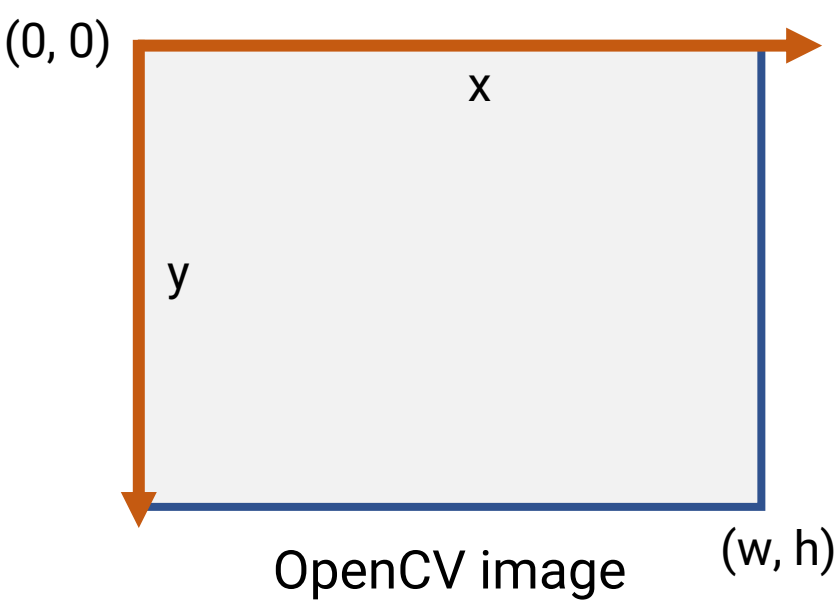
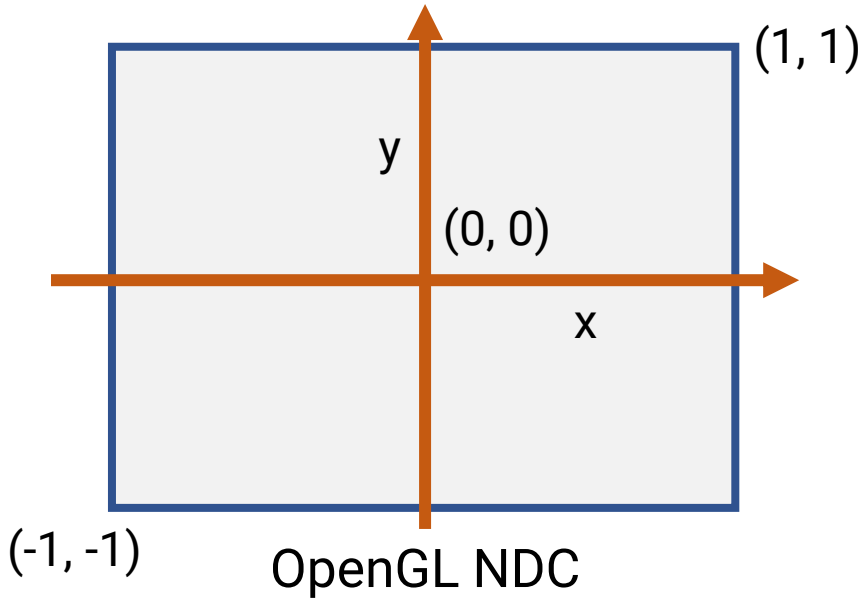
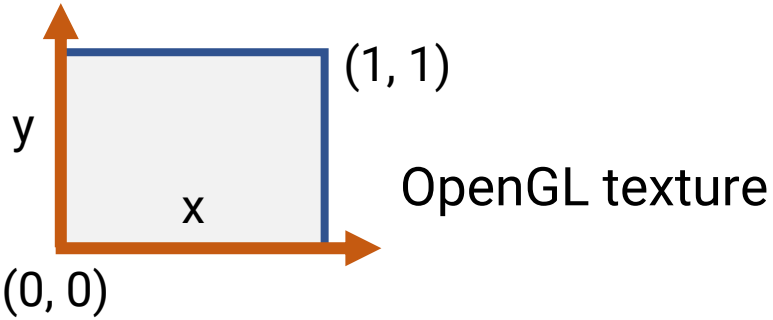


Image Coordinate

- The coordinate of a 2D image depends on libraries







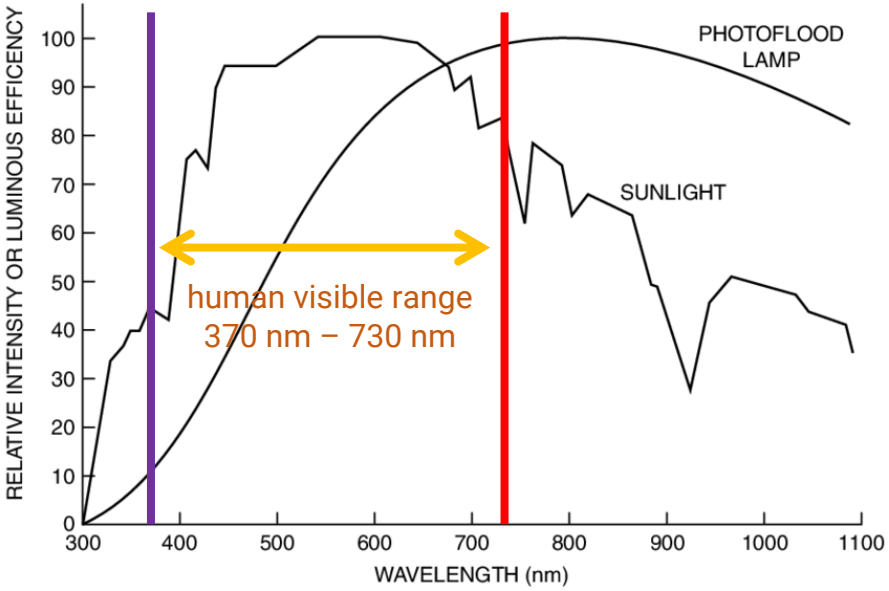
Color

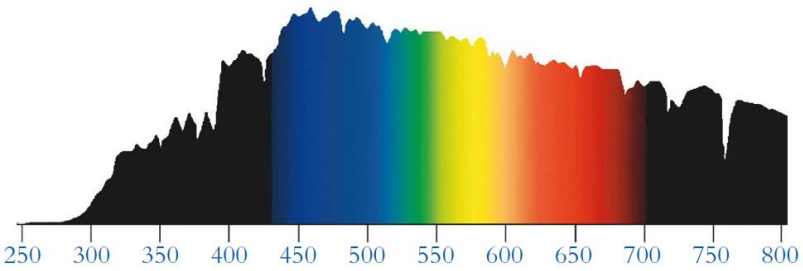
Color Science

- Color is a common experience for humans, but being a rather complex phenomenon
- Color science is a topic that attempts to relate the **subjective sensation** of color to **measurable** and **reproducible** physical phenomena

Spectral Power Distribution

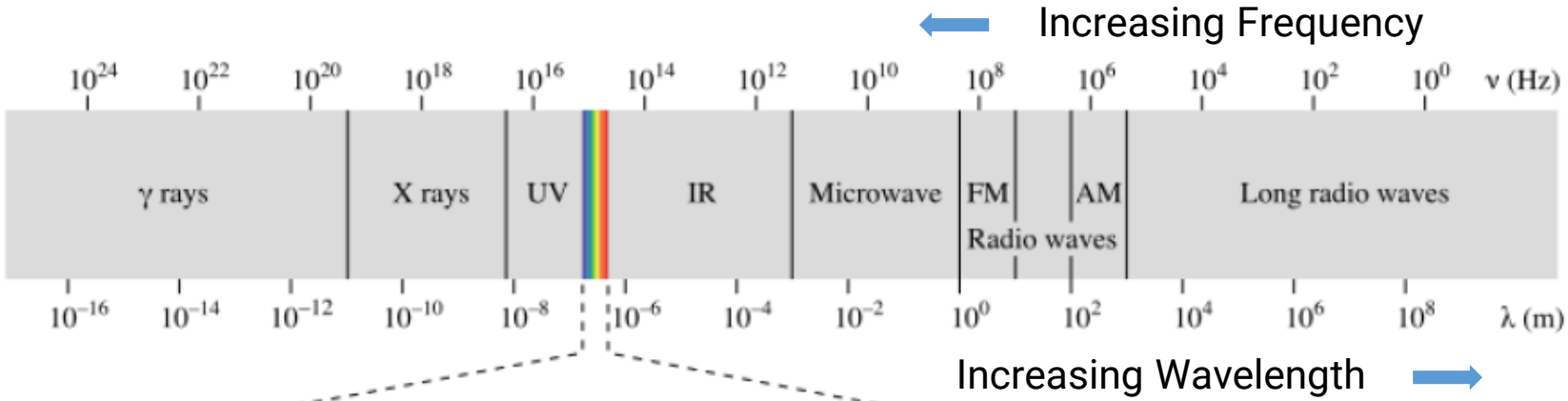
- Light is an electromagnetic wave, and we can measure its wavelength and intensity
- **Spectral power distribution (SPD)** is a description of how the intensity of light varies with its wavelength



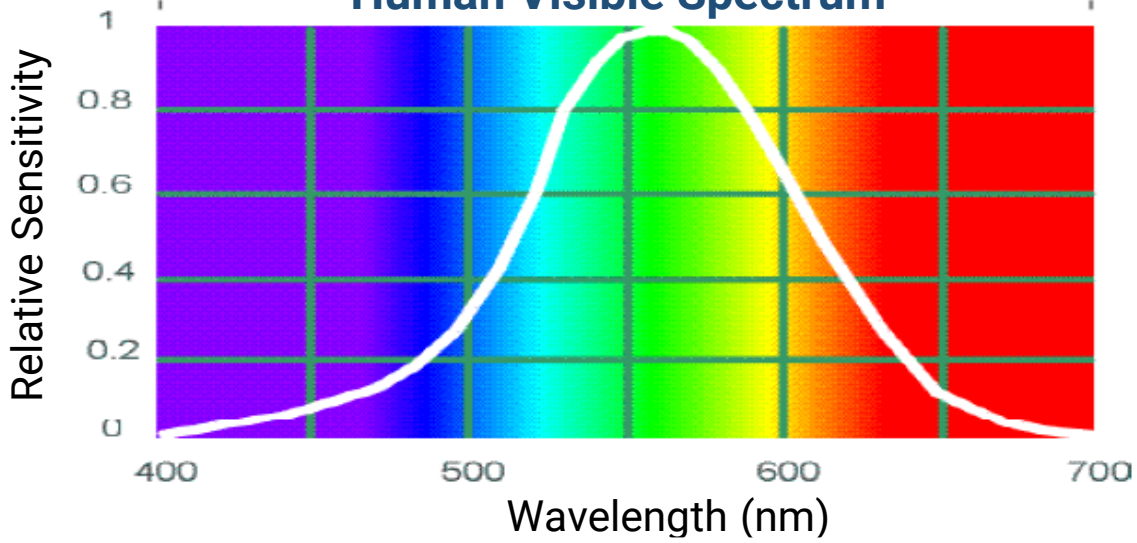


SPD of daylight

Spectral Power Distribution (cont.)



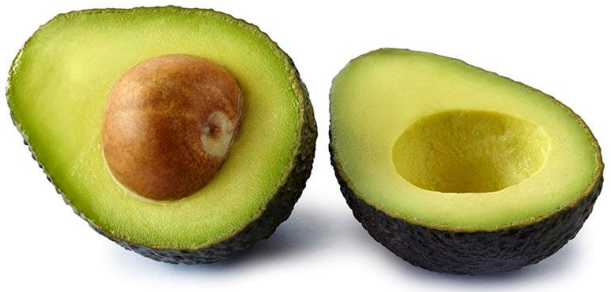
Human Visible Spectrum

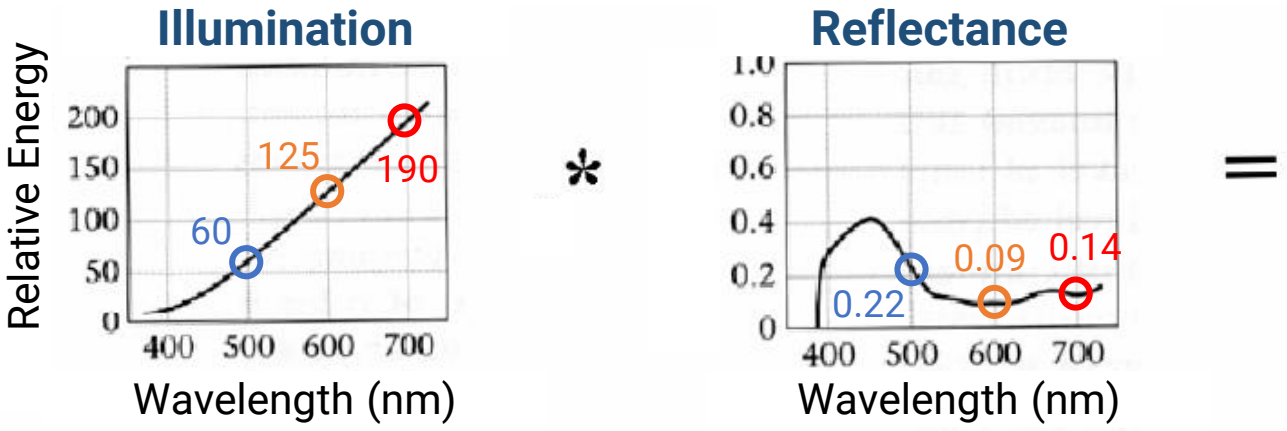


Human Luminance Sensitivity Function

Color

- Reflected color is the result of interaction of **light source spectrum** with **surface reflectance**



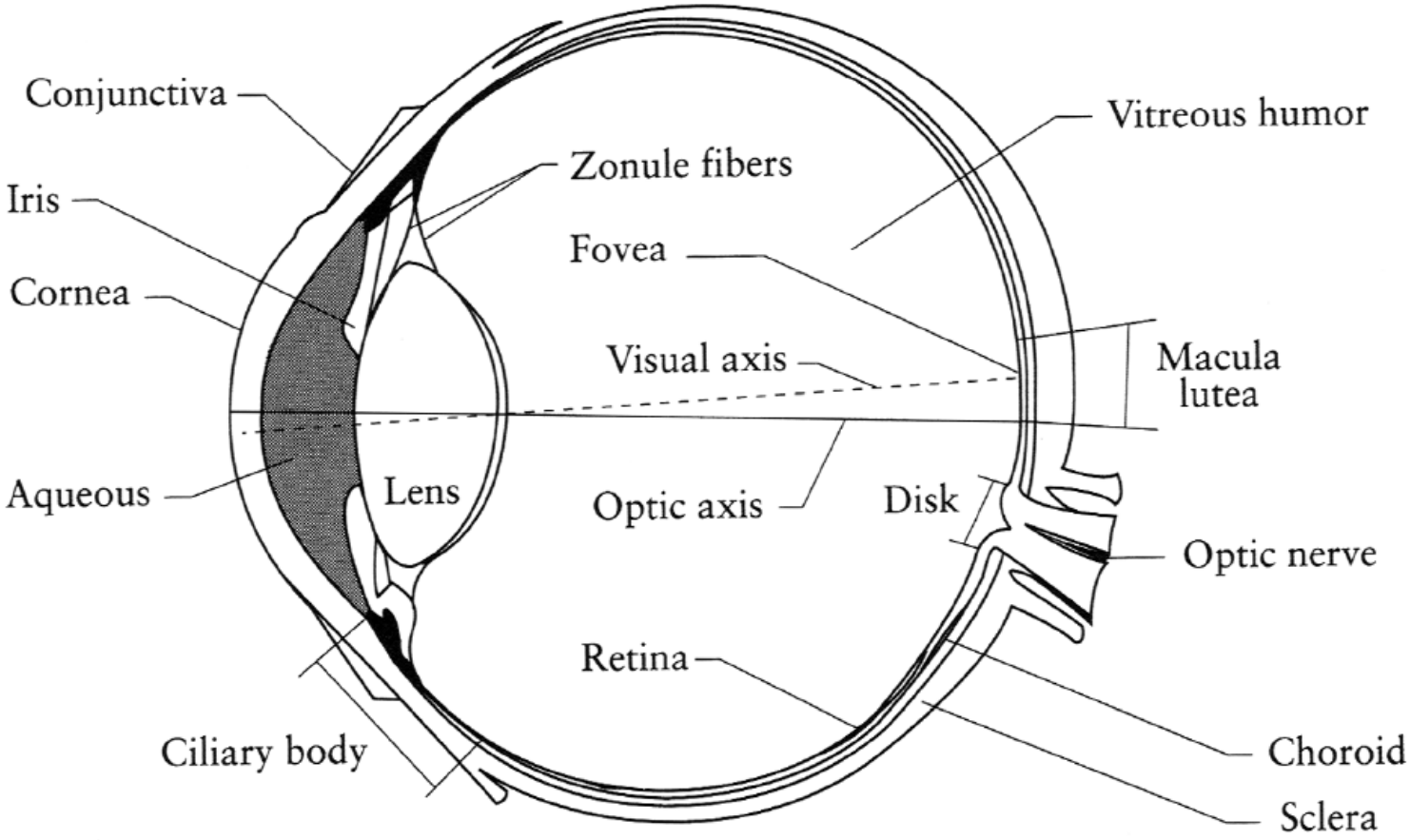


Tristimulus Theory

- SPDs are too cumbersome for representing the color in computer graphics
- Need a more compact, efficient, and accurate way to represent color signals
  - Find proper basis functions to map the infinite-dimensional space of all possible SPDs to the **low-dimensional space of coefficients**
- We use the **tristimulus theory**
  - All visible SPDs can be accurately represented with **three values**

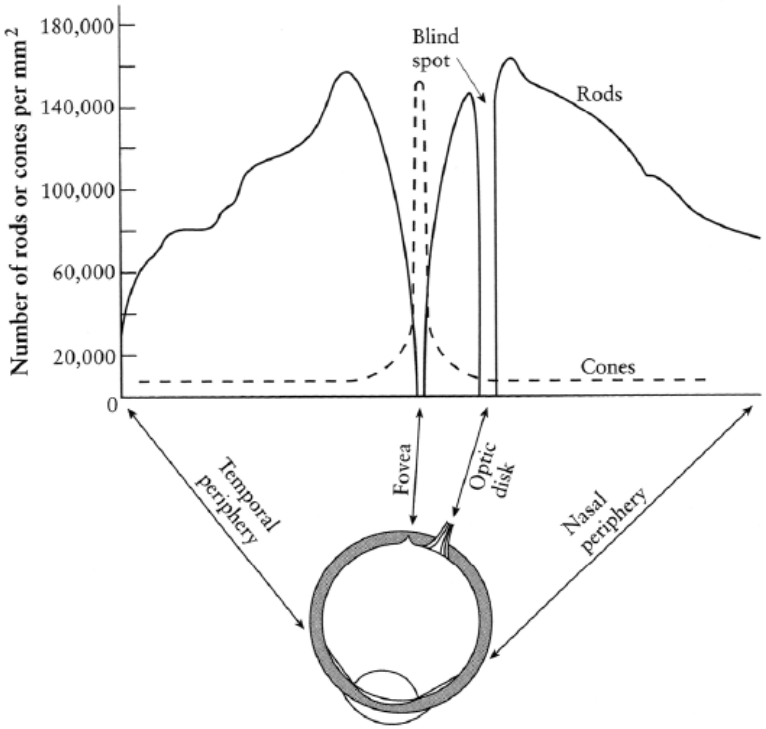
= Any color can be specified by just three values, giving the weights of each of the three components

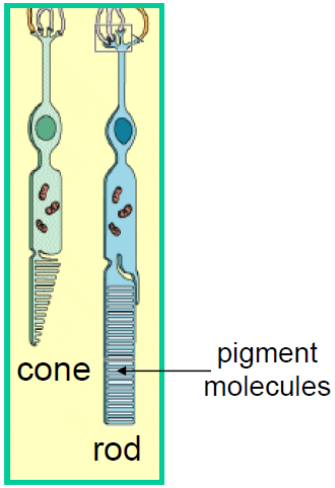
Human Eye

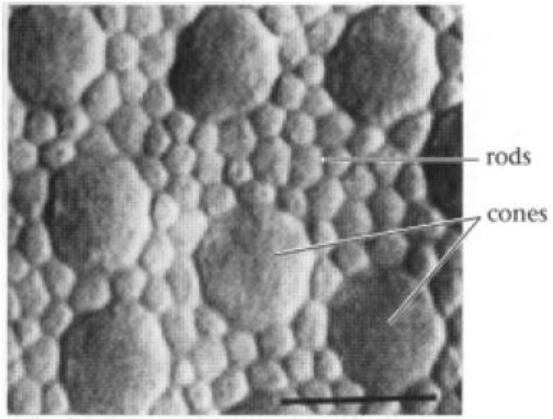

Conjunctiva
Iris
Cornea
Aqueous
Lens
Ciliary body
Zonule fibers
Fovea
Visual axis
Optic axis
Retina
Vitreous humor
Macula lutea
Disk
Optic nerve
Choroid
Sclera

Rods and Cones

- Two types of cells on the retina: rods and cones
  - **Rods:** responsible for **intensity (125M)**
  - **Cones:** responsible for **color (6M~7M)**

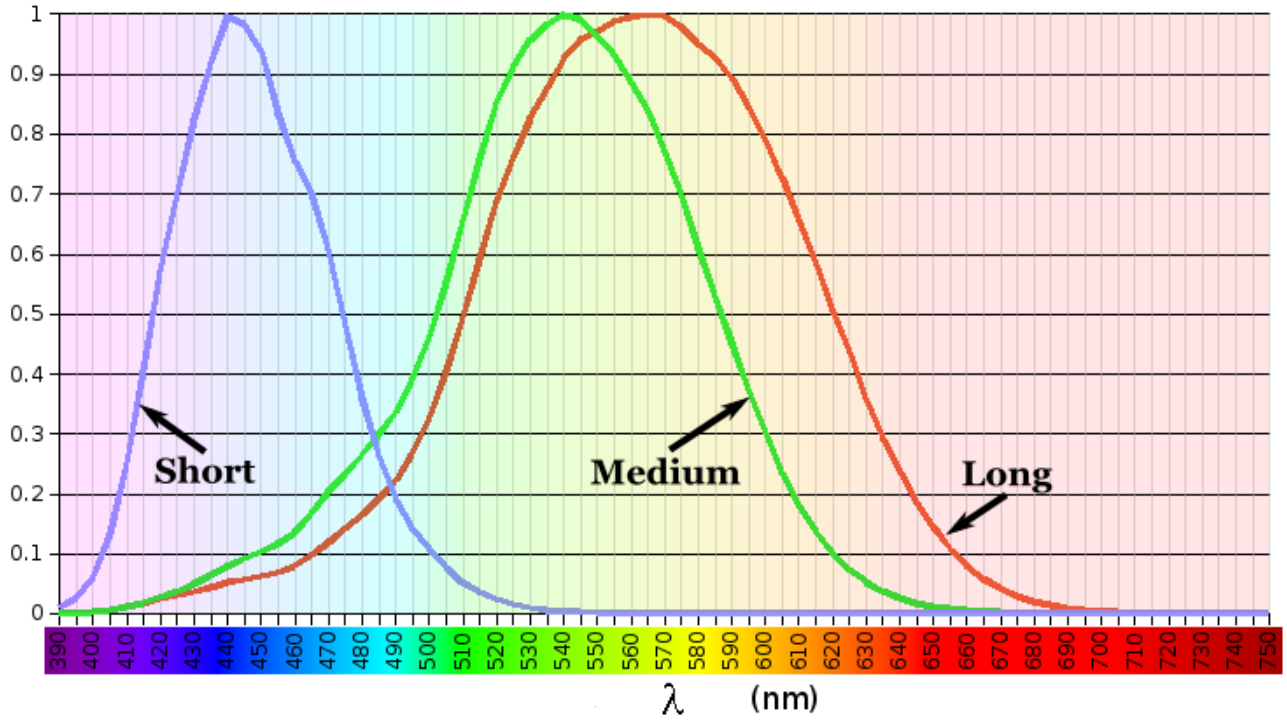






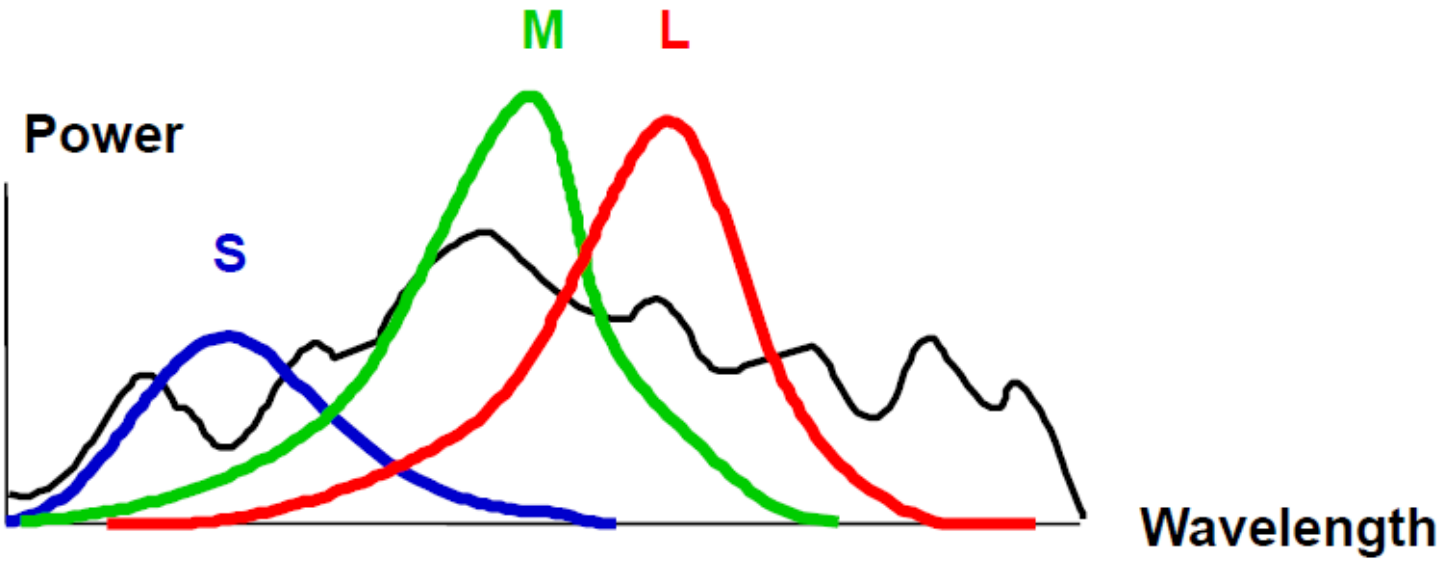
Three Types of Cone Cells

- L-cones: 564 nm (Long)
- M-cones: 534 nm (Medium)
- S-cones: 420 nm (Short)



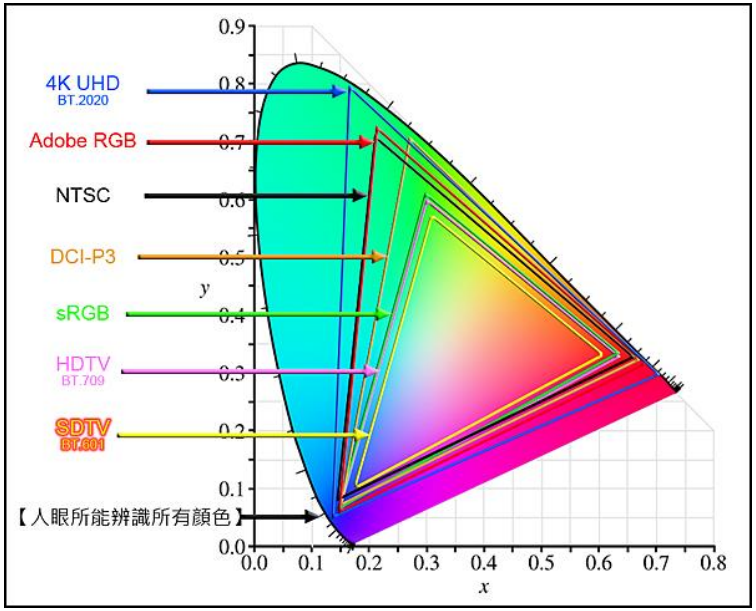
Color Perception

- Rods and cones act as **filters** on the spectrum
  - To get the output of a filter, multiply its response curve by the spectrum, integrate over all wavelengths
  - Each cone yields one number and we just got three numbers in total!



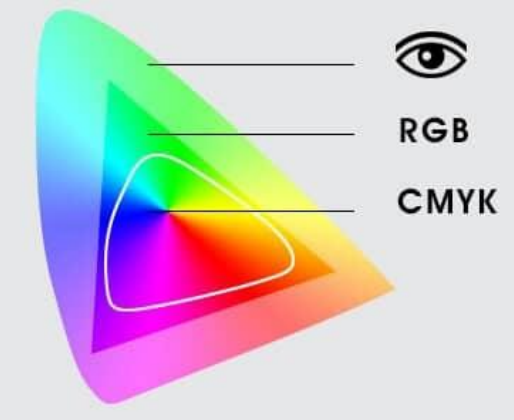
RGB Color Model

- The **tristimulus theory** and the **response curves of LMS cones** lead to the RGB model
  - Any color can be represented by three values, giving the proportions of red (R), green (G), and blue (B) light
  - However, no standard SPDs are defined for R, G, and B



RGB Color Gamut

- Although the RGB model provides a good representation of color, it cannot represent all visible colors of the human eye
- RGB primaries do produce the **largest** gamut from the simple addition of three primaries
- Red, green, and blue are called the **primary color** of the light (additive mixing)

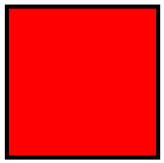


RGB Color Model Representation

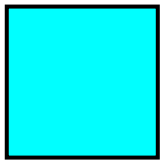
- We can write a color with the RGB model in the form of

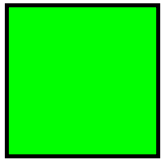
  (r, g, b),

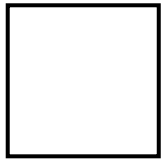
Where r, g, b are the **amounts (proportion of the pure light)** of red, green, and blue light making up the color

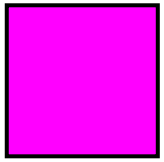

Red
(100%, 0%, 0%)

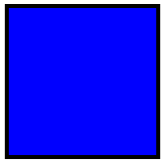

Black
(0%, 0%, 0%)

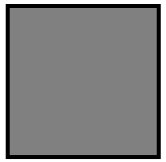

Cyan
(0%, 100%, 100%)

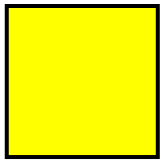

Green
(0%, 100%, 0%)


White
(100%, 100%, 100%)


Magenta
(100%, 0%, 100%)


Blue
(0%, 0%, 100%)

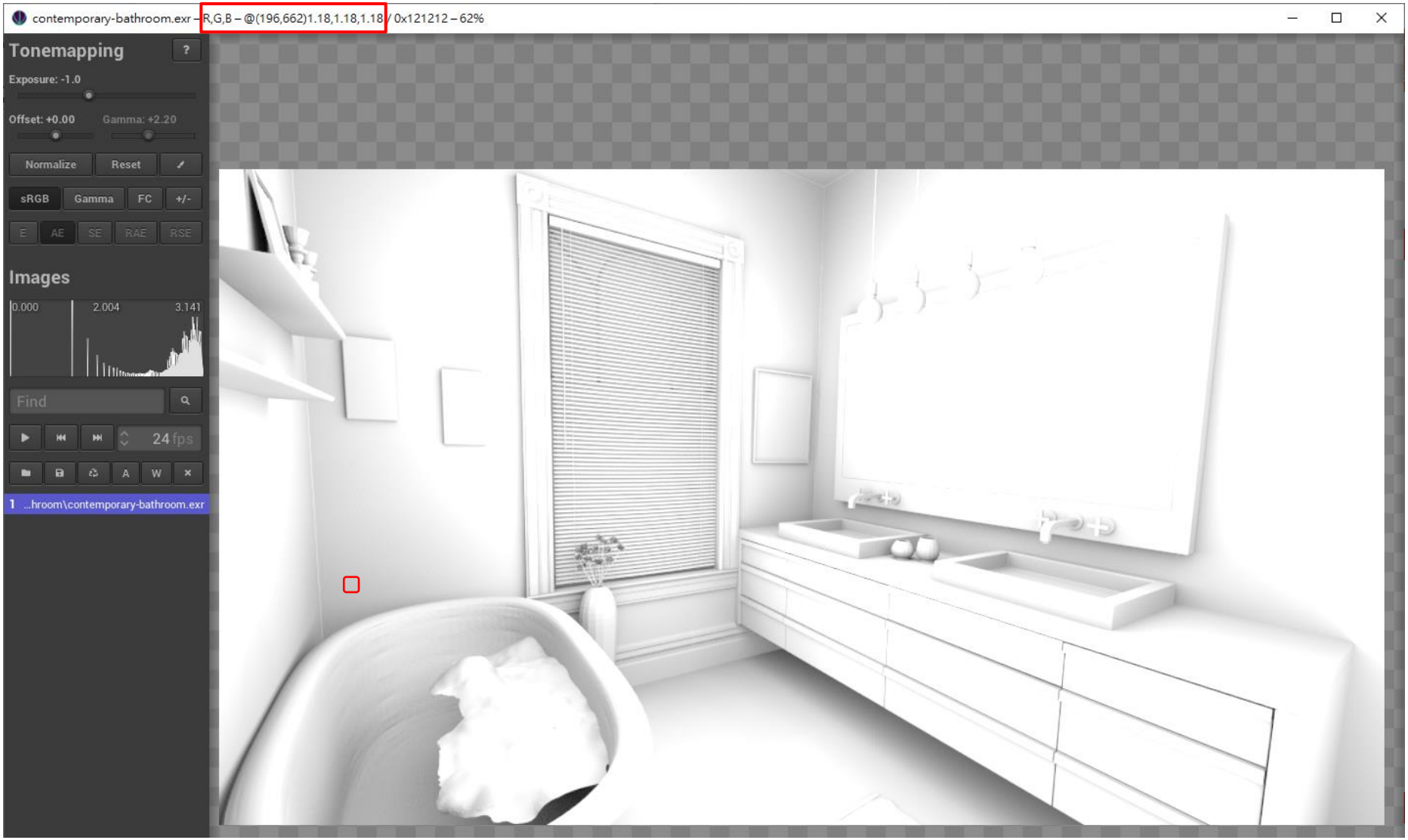

Gray
(50%, 50%, 50%)


Yellow
(100%, 100%, 0%)

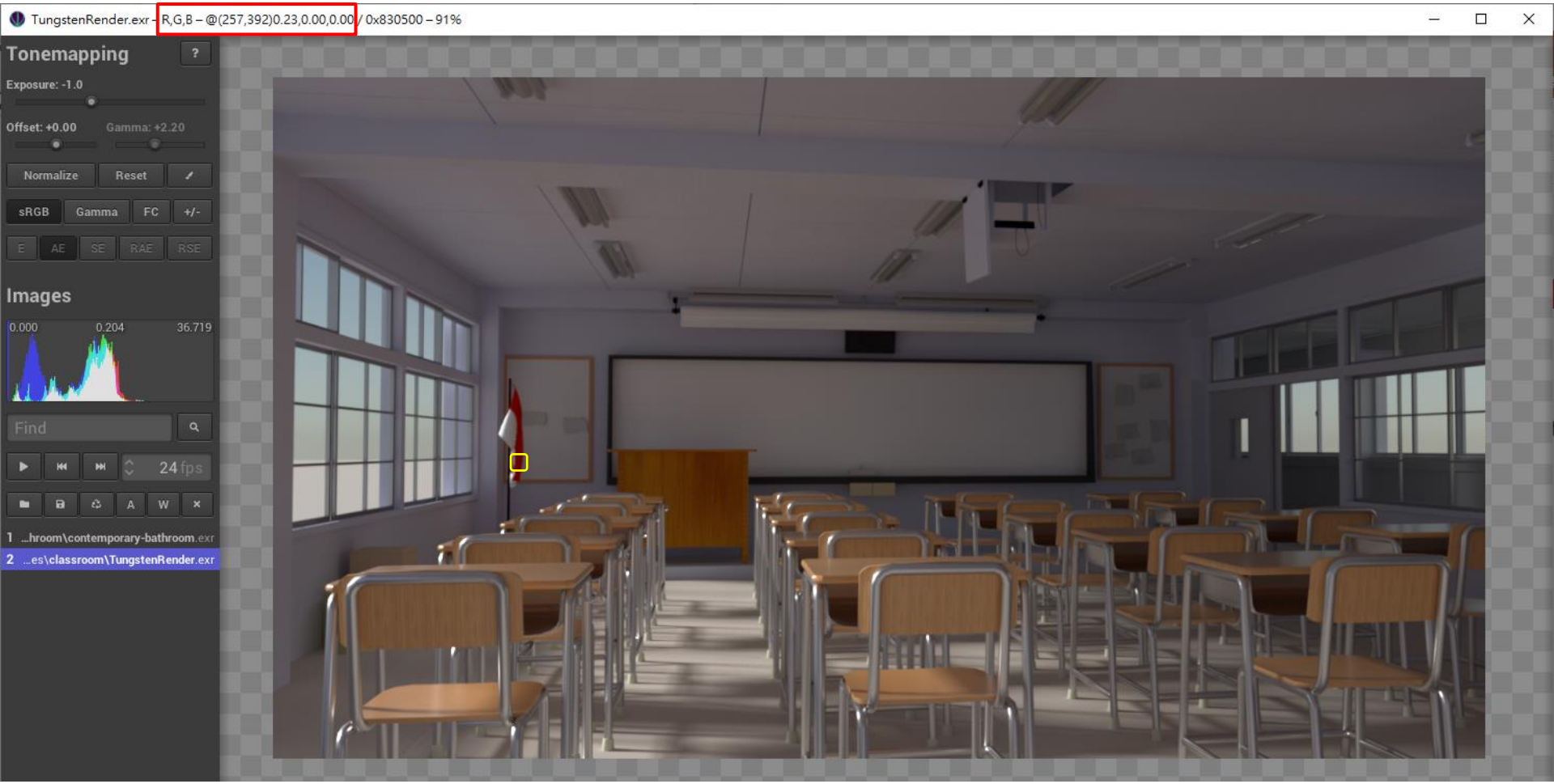
Color Depth

- In digital representation, we must choose the **number of bits** used for a color
- The most common choice is **8 bits (1 byte)** for each primary color, making 24 bits (3 bytes) in total
  - The range of value falls within [0, 255], making a total 256 x 256 x 256 = 16777216 different colors **(24 bit color depth)**

The Rendered Images (Gray Scale)



The Rendered Images (Color)



Any Questions?