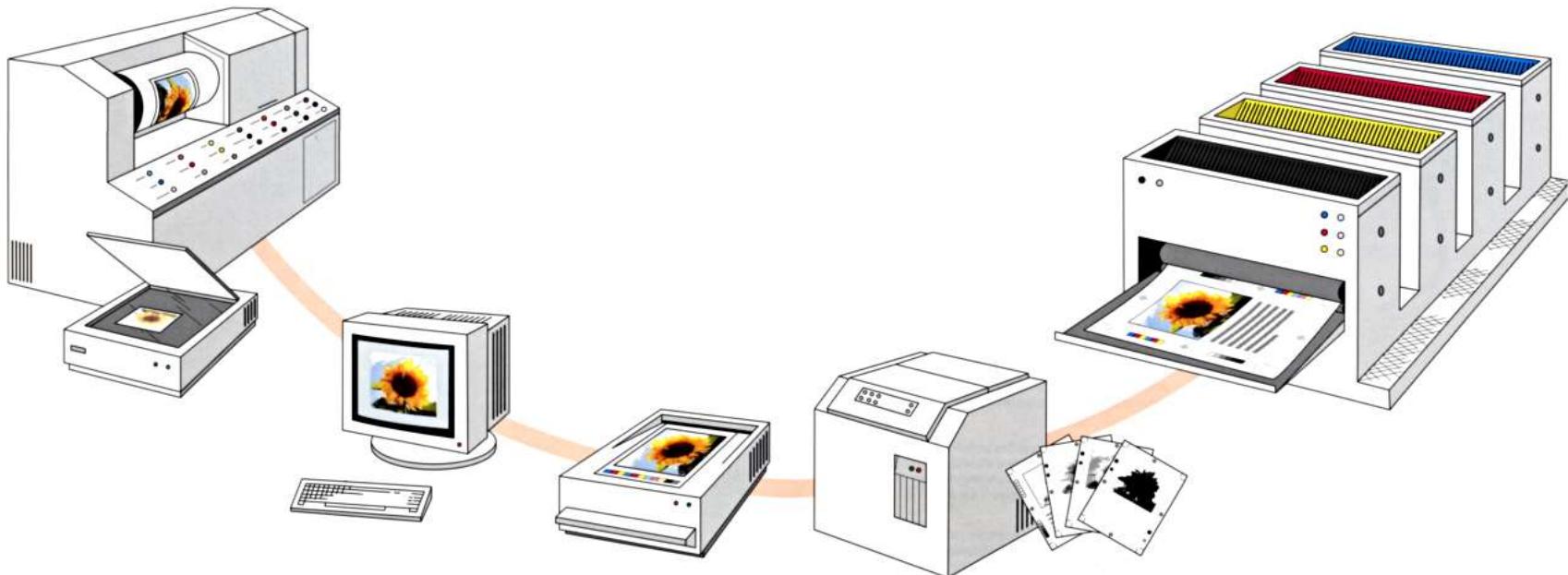
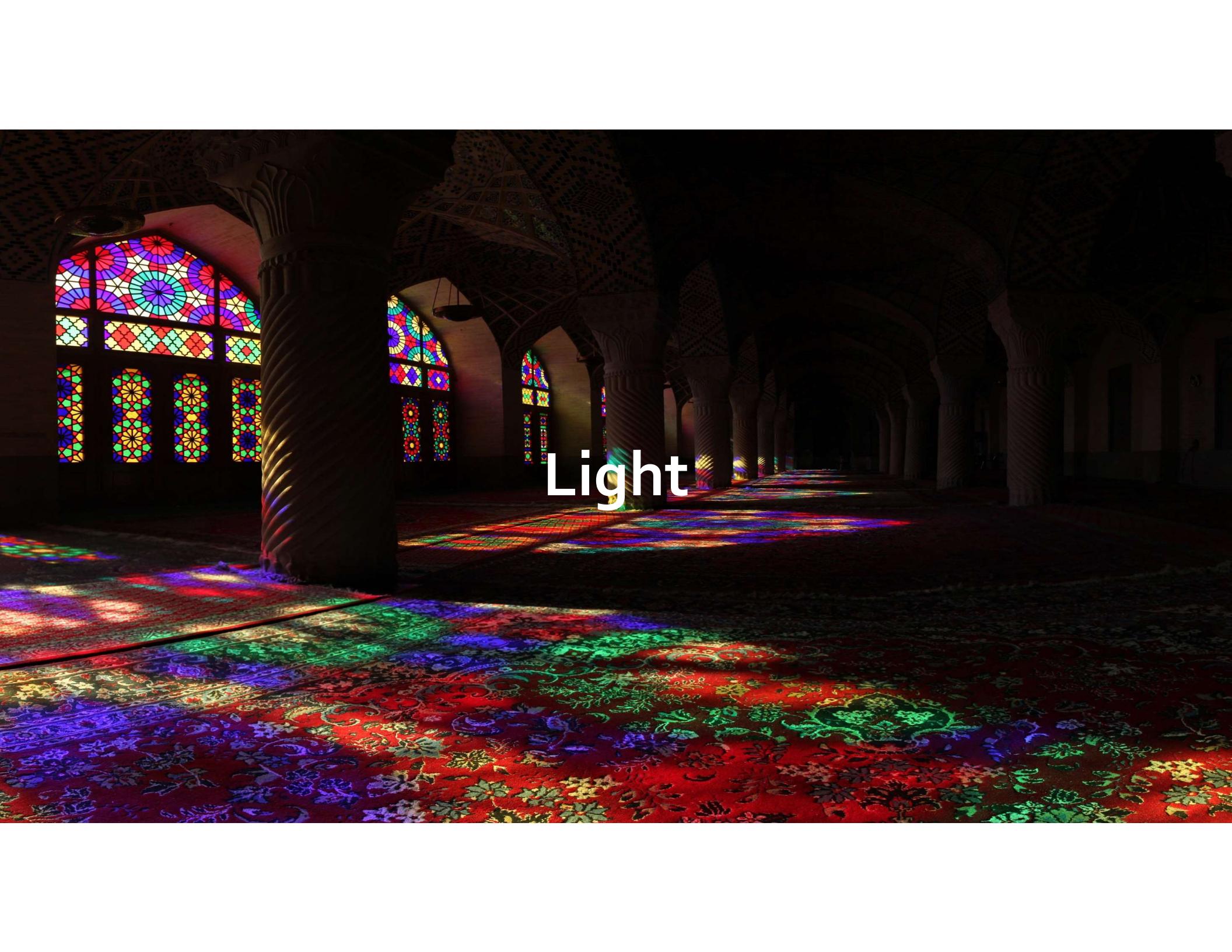
A photograph of the interior of a mosque, likely the Nasir Al-Mulk Mosque in Shiraz, Iran. The image shows a long, dark aisle with a large, ornate arched ceiling. On the left, a series of arched windows are filled with vibrant, multi-colored stained glass patterns. Light from these windows filters down onto a large, patterned carpet on the floor, creating a play of colors and geometric shapes. The overall atmosphere is one of deep shadow punctuated by bright, colorful light.

Color and Light

Color - Why Do We Care?

- Computer Graphics output is number of colored pixels
- Understand how/why color is represented

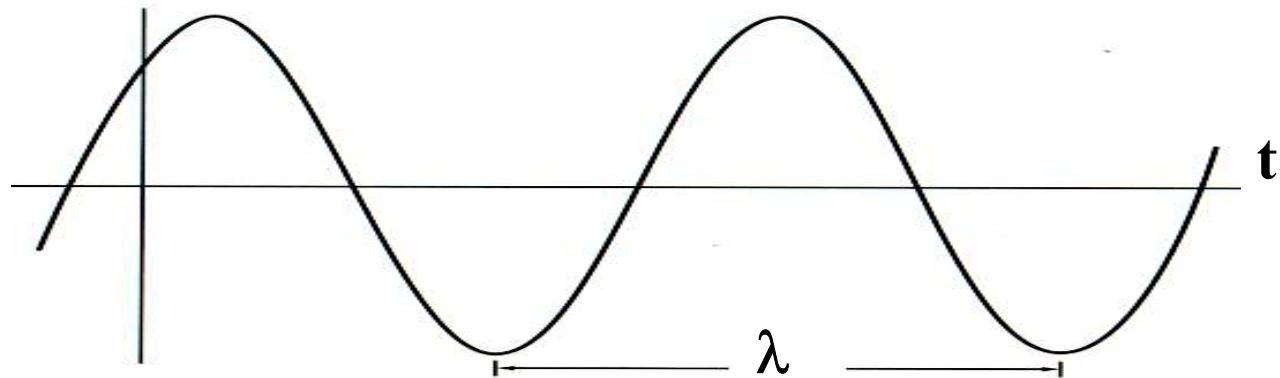




Light

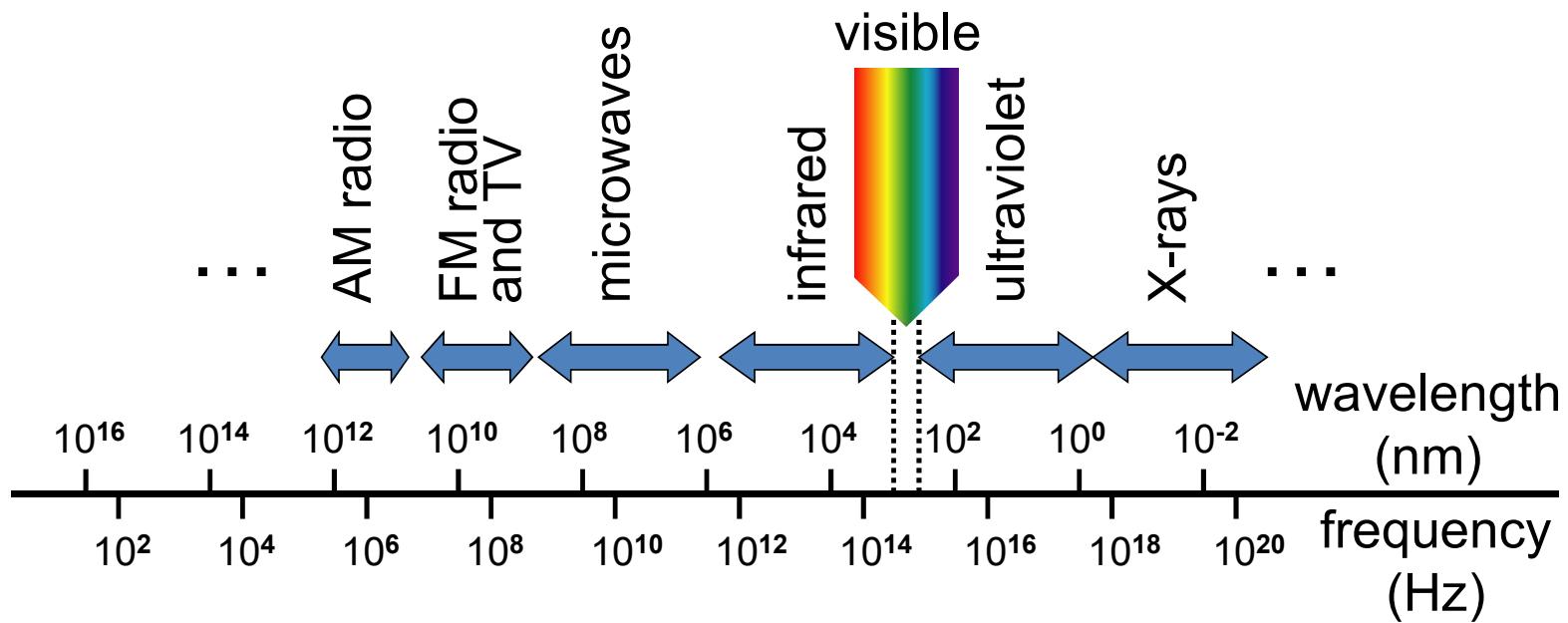
What is Light?

- Light is an electromagnetic Wave
- Monochrome light (e.x.: laser) has a single frequency f or wavelength λ
- $c = \lambda f$ (c = speed of light in medium)
 - Shorter wavelength equals higher frequency



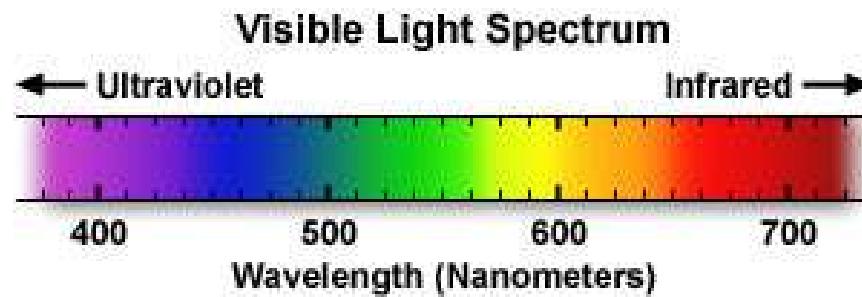
Light – An Electromagnetic Wave

- Frequency band of electromagnetic spectrum



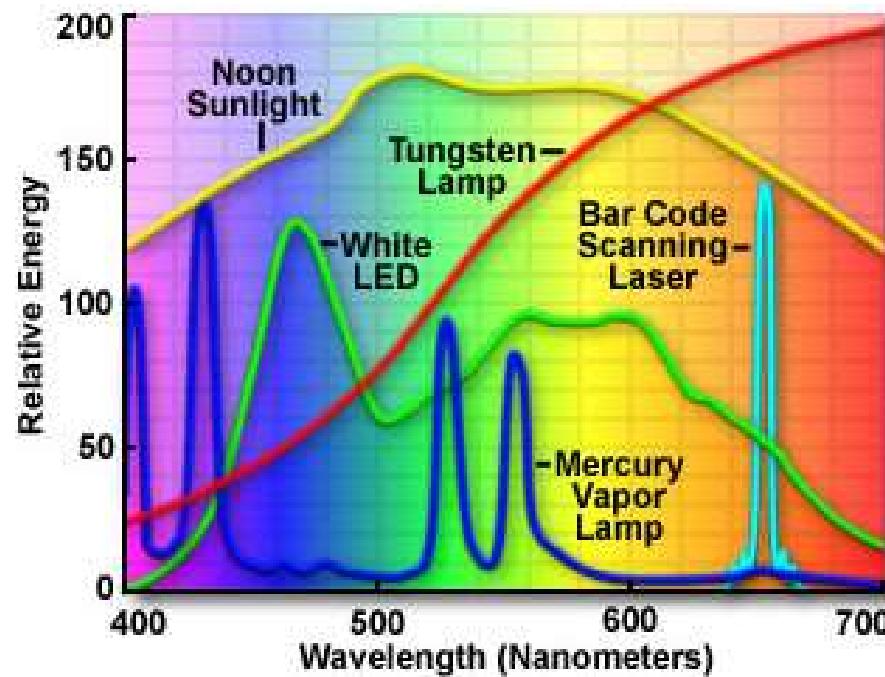
Light – An Electromagnetic Wave

- Frequency band of electromagnetic spectrum



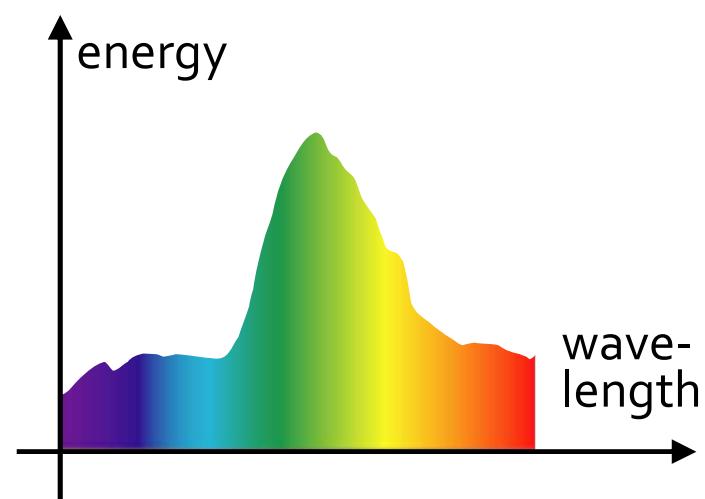
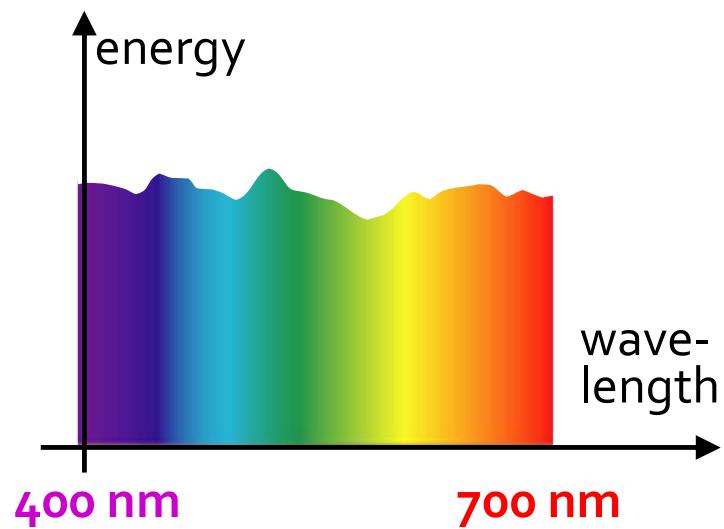
Light – Spectrum

- Normal light mixture of different frequencies
- Distribution of wavelength intensities is called *spectrum*



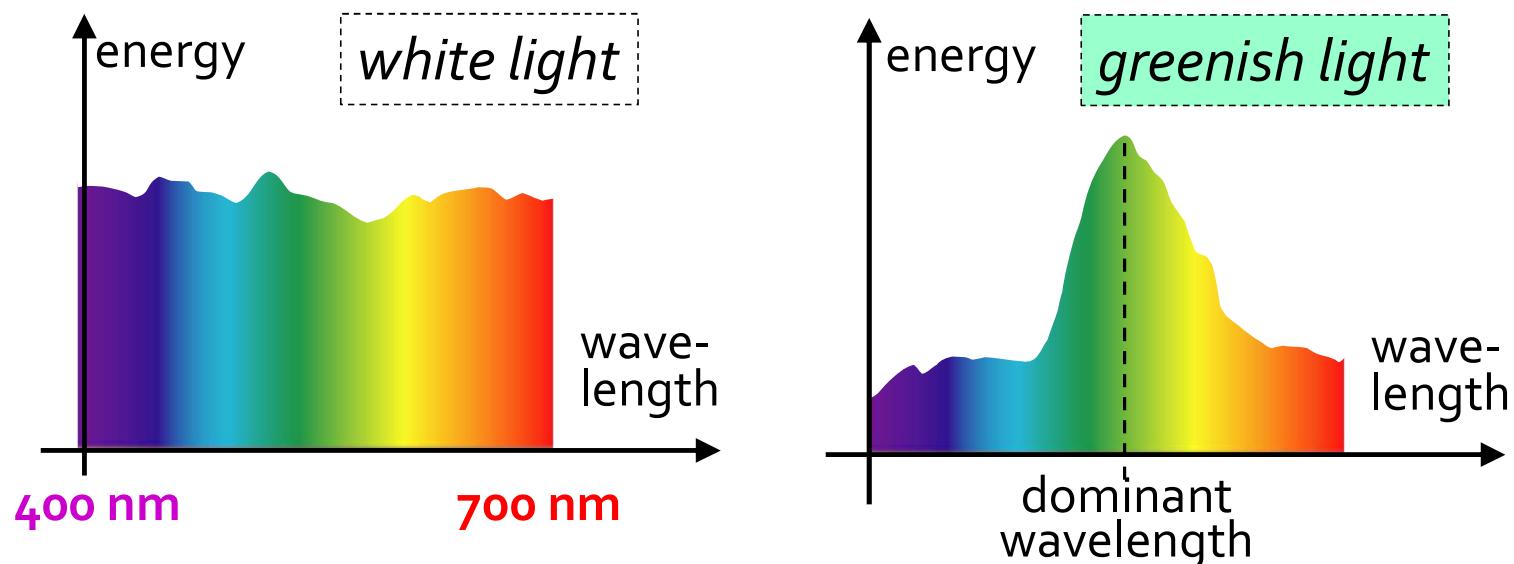
Brightness

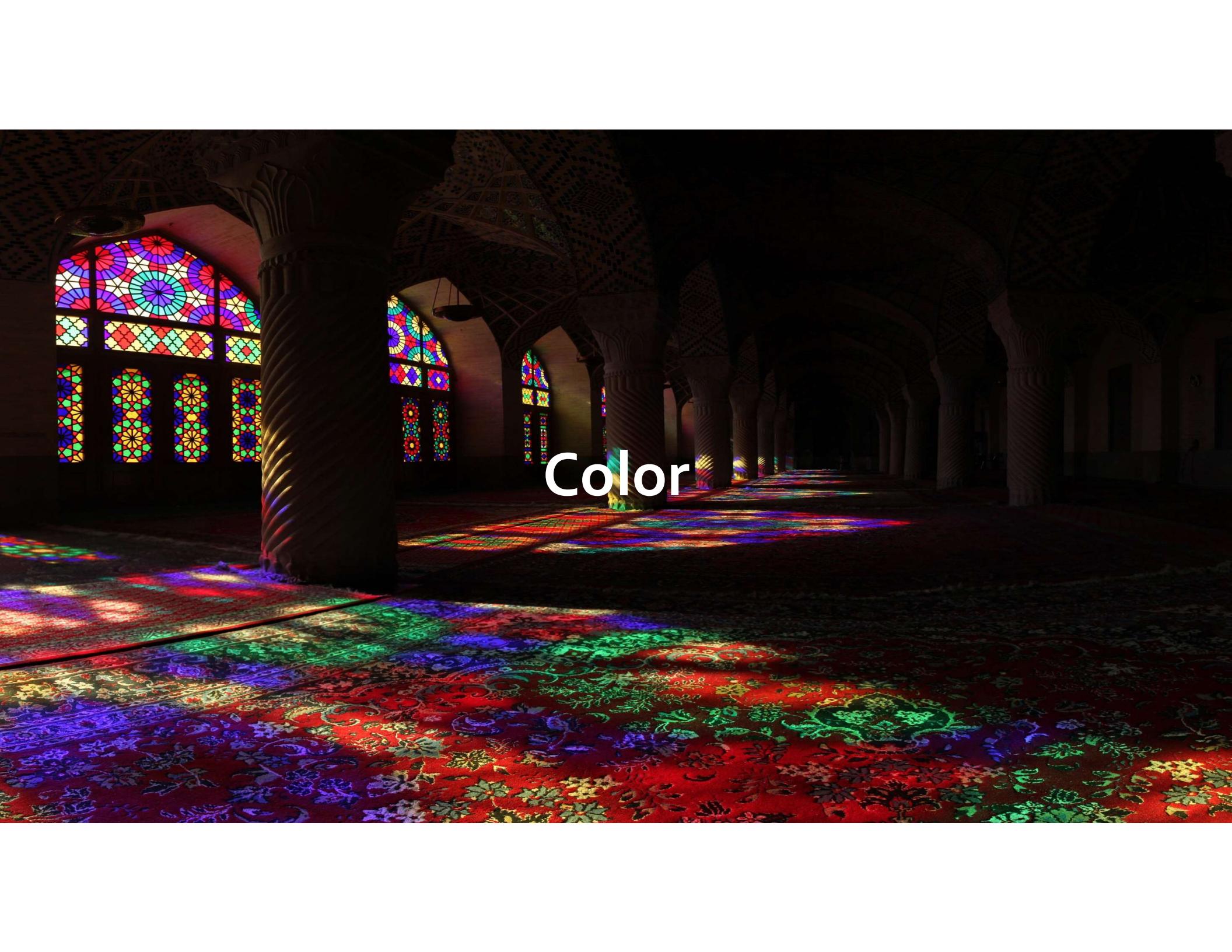
- Area under the curve



Dominant Wavelength

- Main frequency (hue, color)

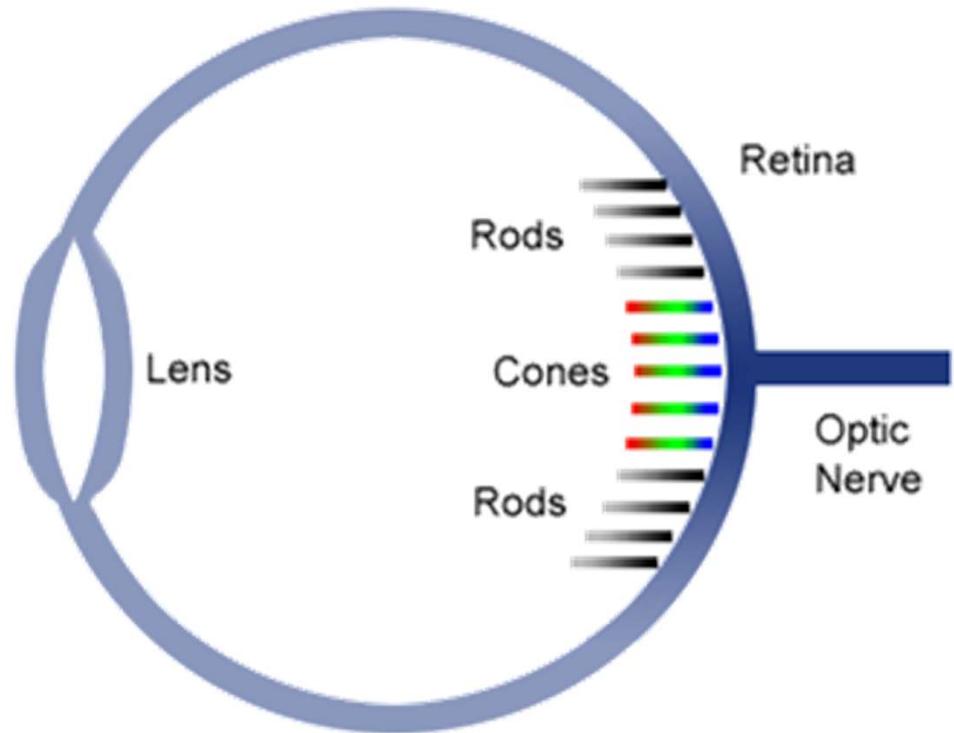


A photograph of the interior of a mosque, likely the Nasir Al-Mulk Mosque in Shiraz, Iran. The image shows a long, dark corridor with a large, ornate arched entrance on the left. The floor is covered with a large, colorful Persian rug featuring intricate floral patterns in red, green, blue, and gold. Light filters through numerous stained-glass windows in the arches, creating a vibrant play of colors on the floor and walls. The architecture is characterized by its intricate tilework and geometric patterns.

Color

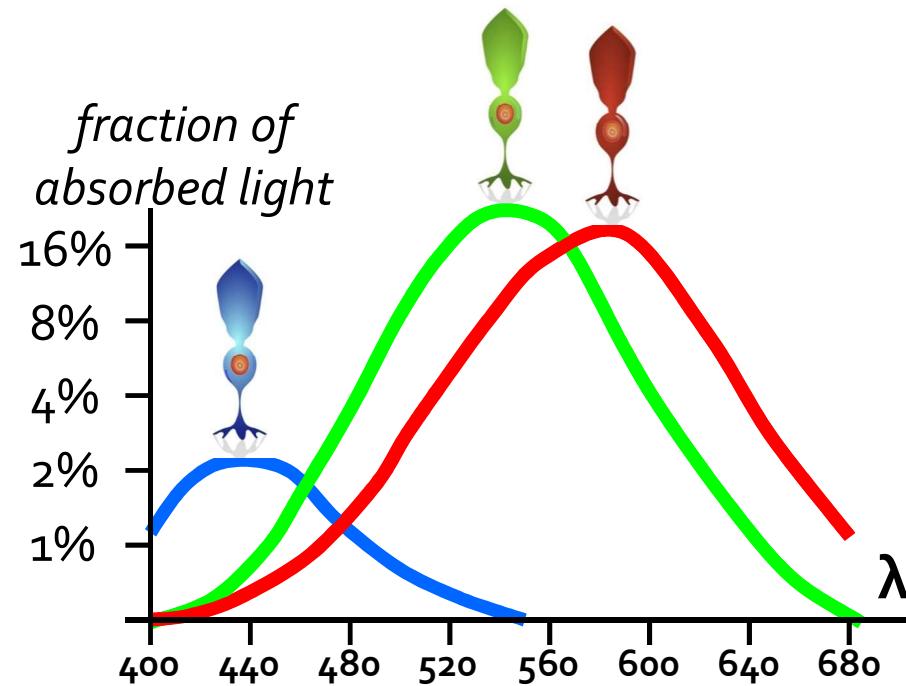
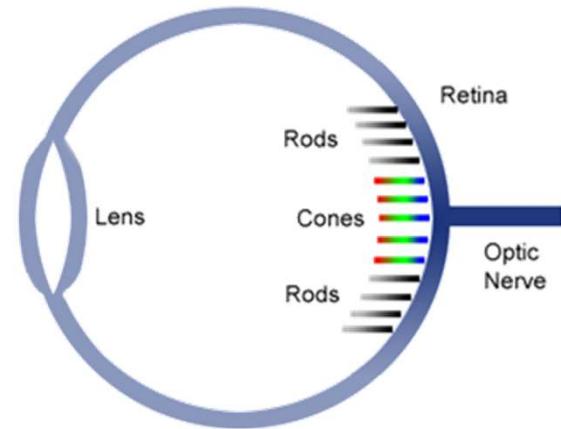
What is Color?

- Characteristic of human visual perception
- Created through stimulation of cone cells in the human eye by light
- Described through color categories, like *red, yellow, ...*
- Other species quite different



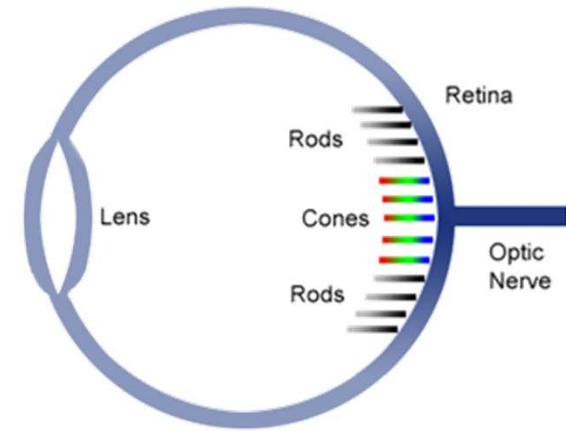
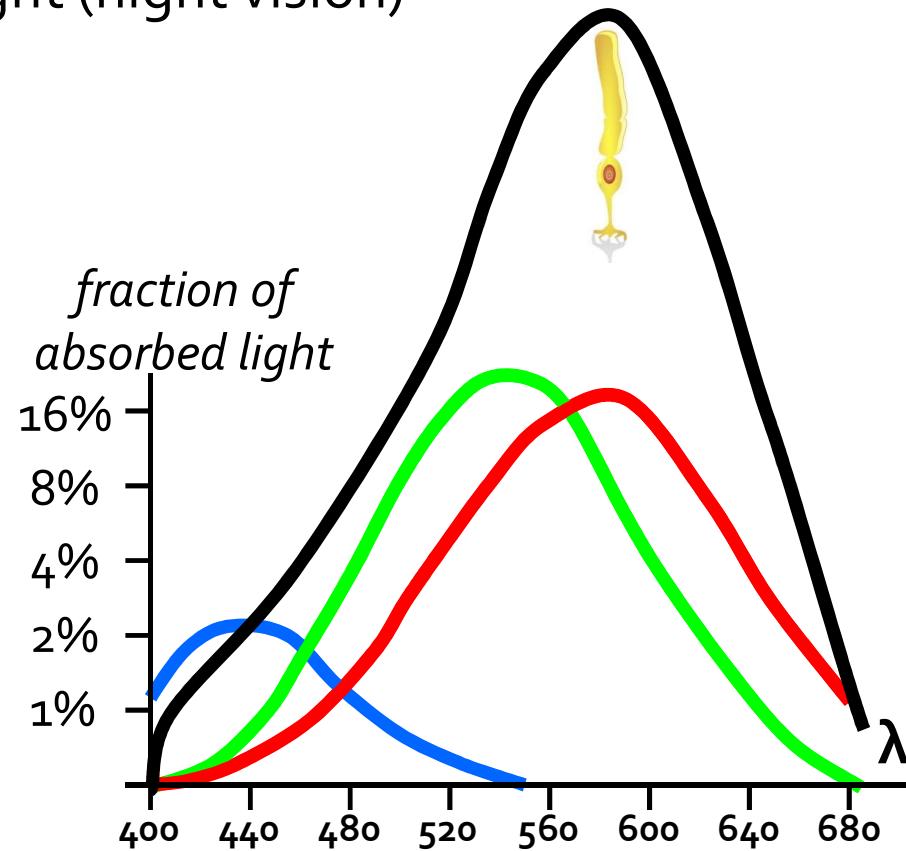
The Human Eye – Cones

- 3 types
- Different wavelength sensitivities (tristimulus)
 - Red
 - Green
 - Blue



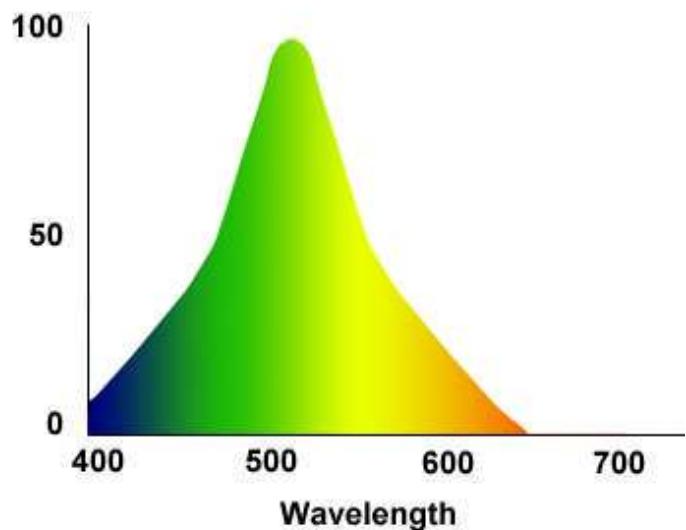
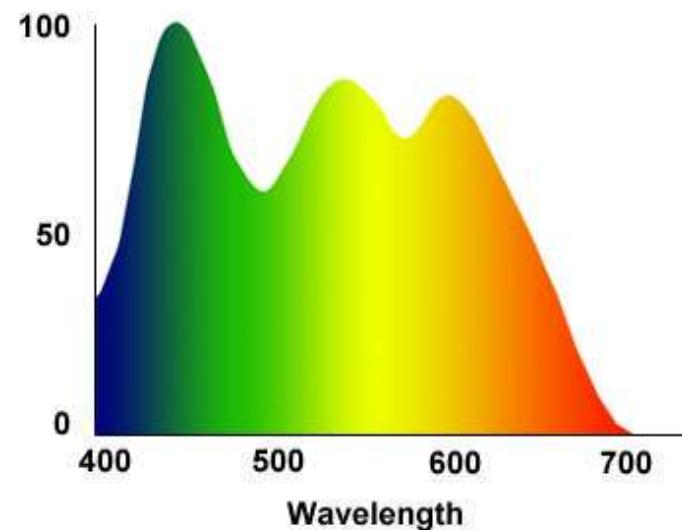
The Human Eye – Rods

- For less intense light (night vision)
- Peripheral vision

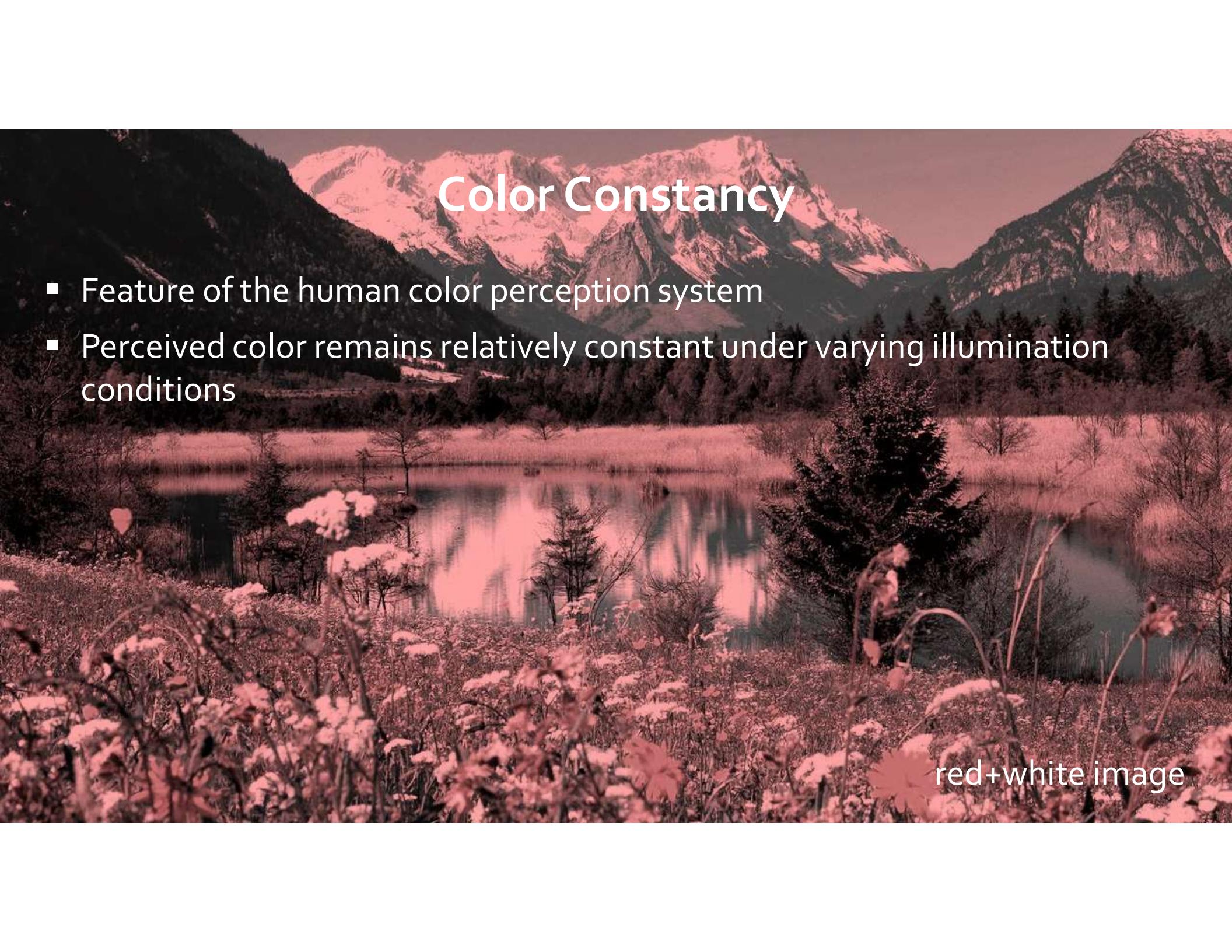


The Human Eye - Adaptation

- Daylight-adapted human eye
- Dark-adapted human eye





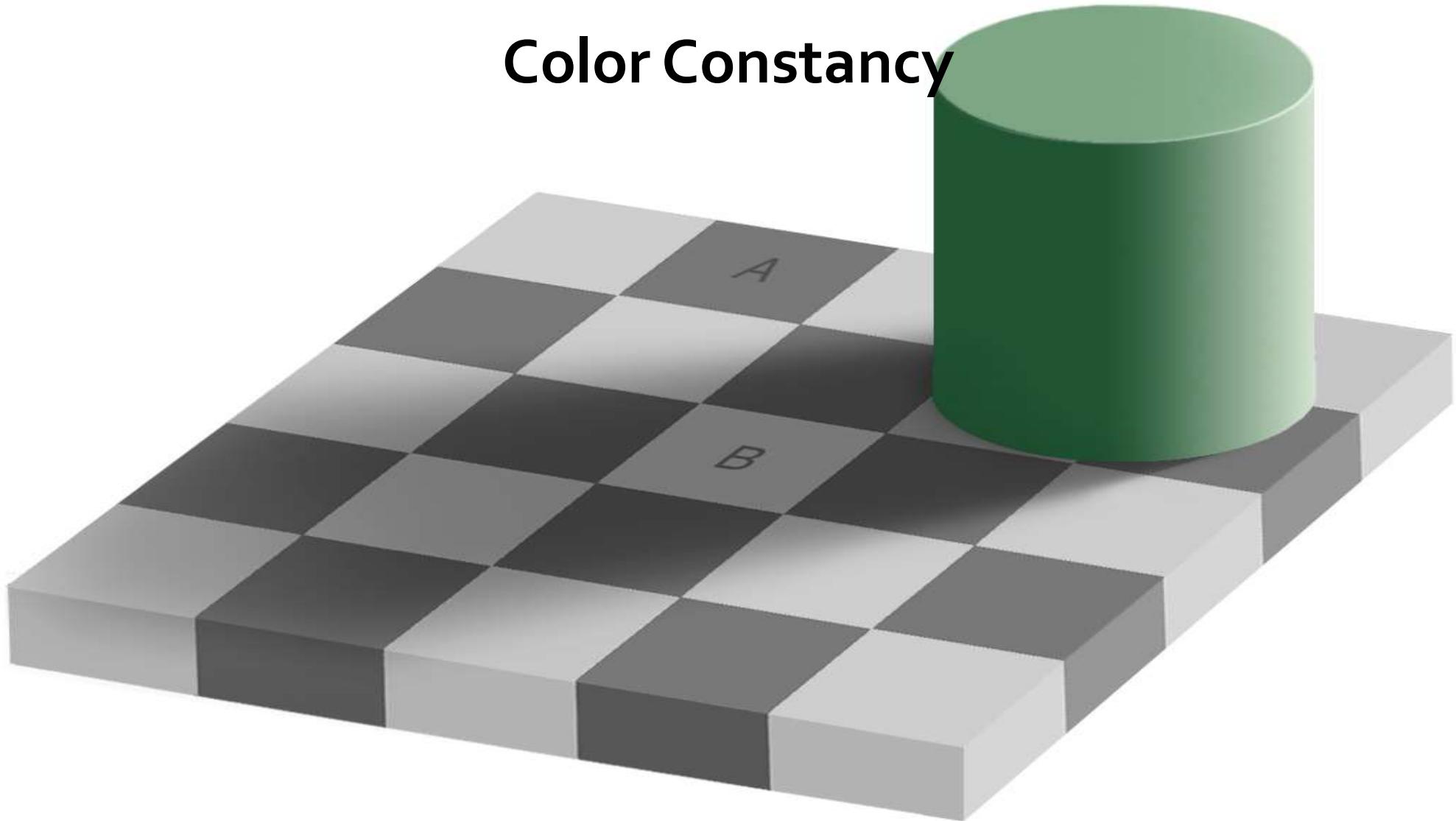
A scenic landscape featuring a range of snow-capped mountains in the background. In the middle ground, there is a calm lake reflecting the surrounding environment. The foreground is filled with white, fluffy flowers, possibly dandelions or similar wildflowers, swaying in the wind. The overall scene is peaceful and natural.

Color Constancy

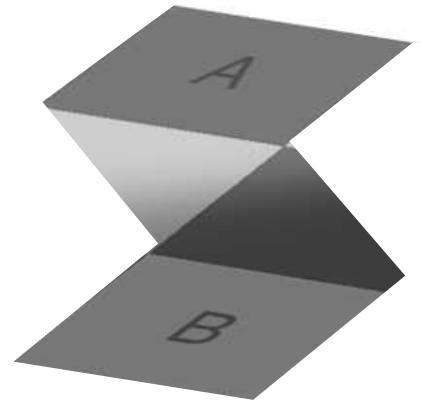
- Feature of the human color perception system
- Perceived color remains relatively constant under varying illumination conditions

red+white image

Color Constancy



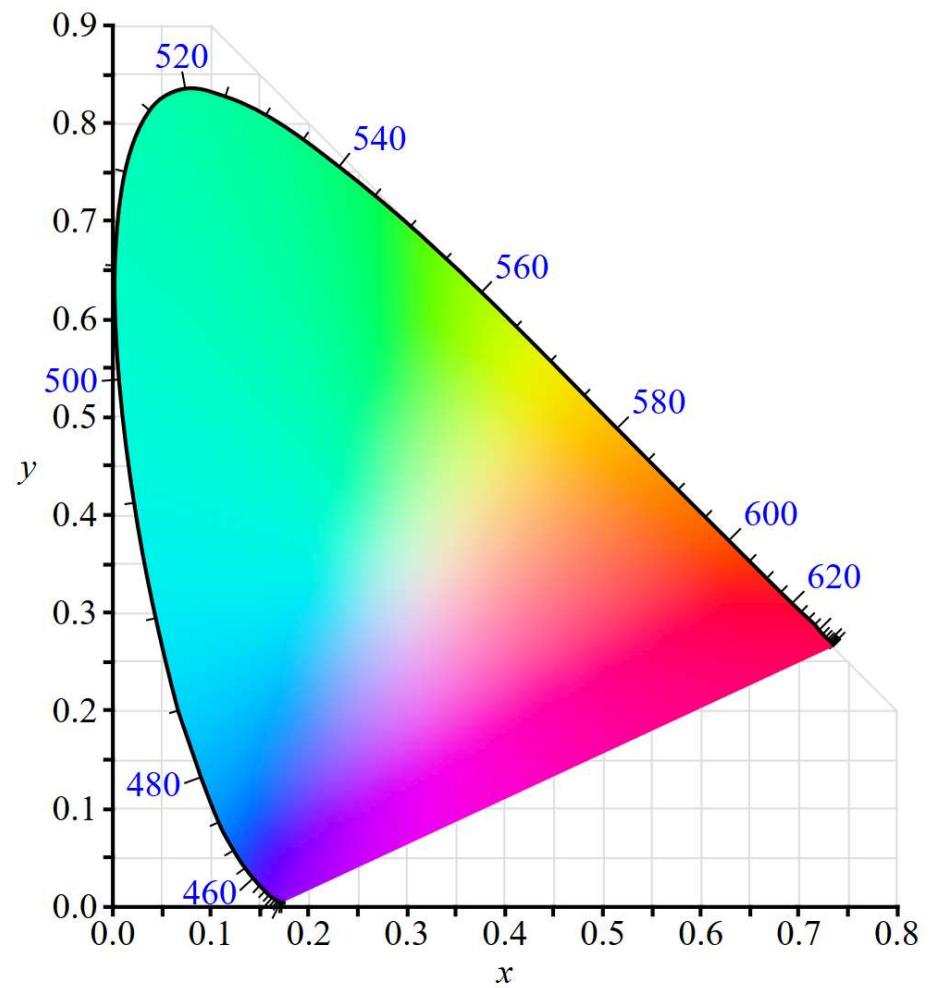
Color Constancy



Color Spaces/Systems

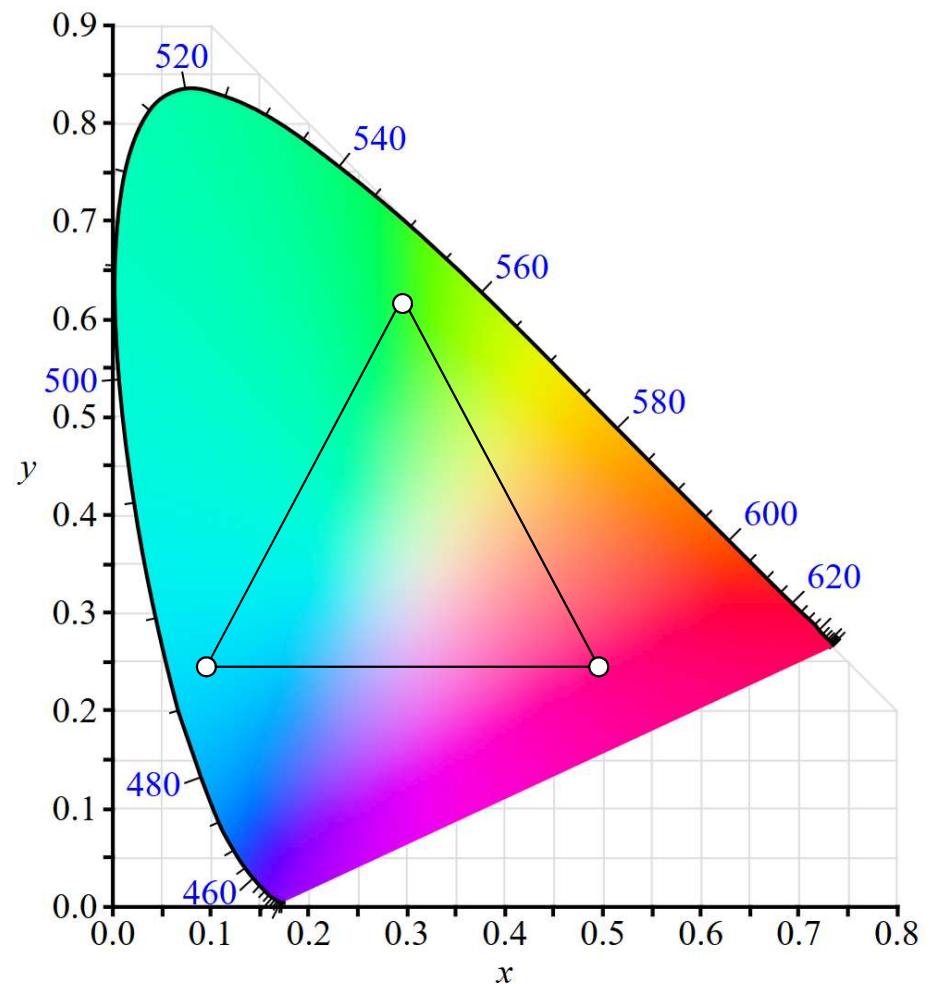
Range of Human Color Perception

- Projected slice is shown
 - CIE 1931 color space chromaticity diagram



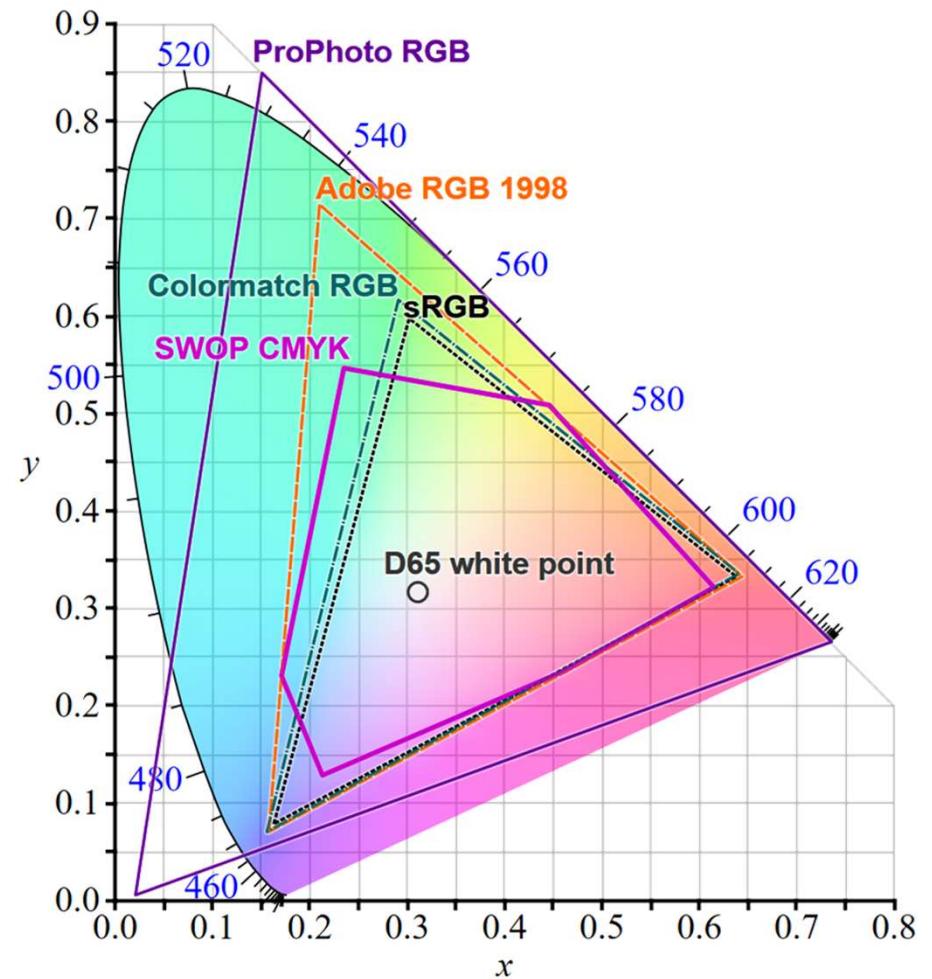
Color Model/Space

- Specific organization of colors
- Identify colors numerically by coordinates
- Pick primaries
- Can describe area between primaries



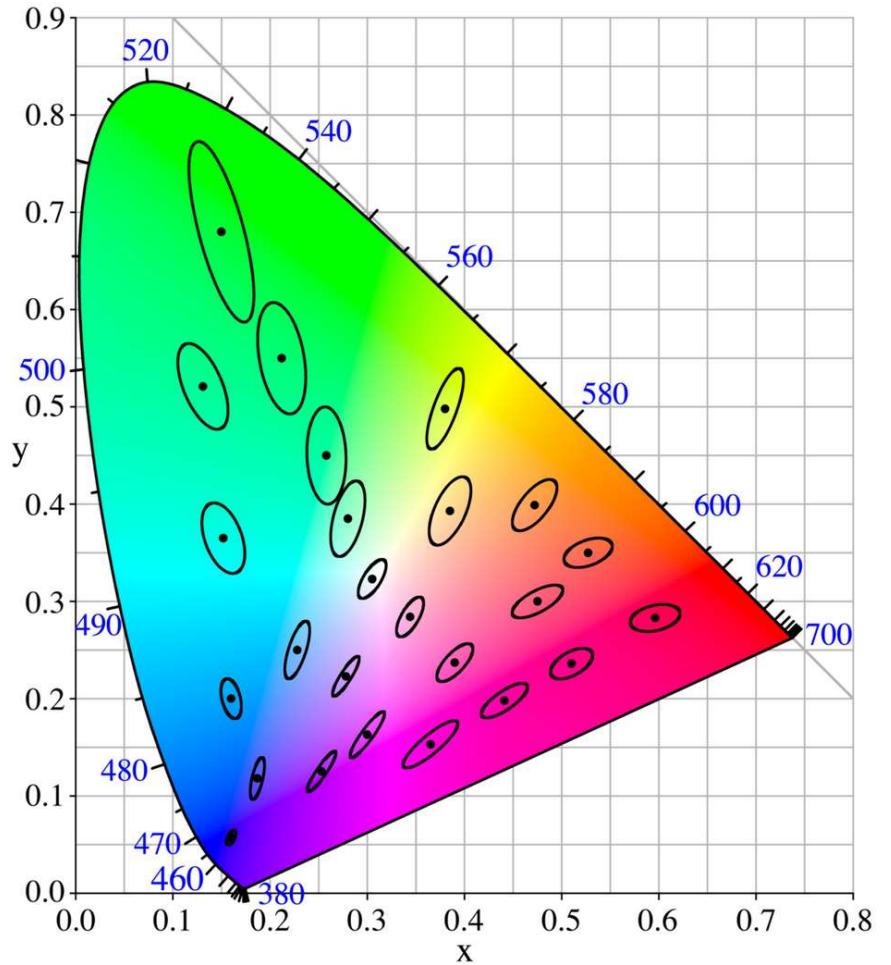
Color Spaces

- Specific organization of colors
- Identify colors numerically by coordinates
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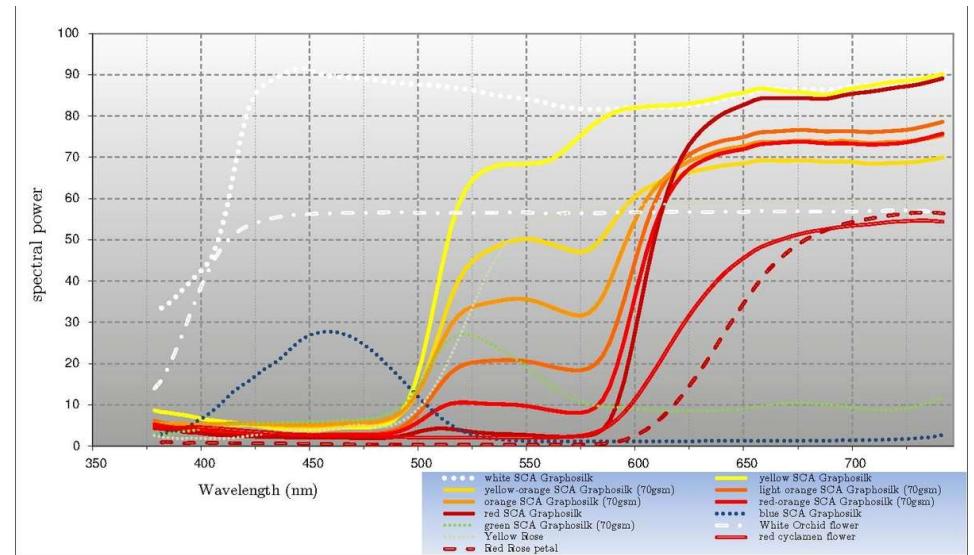
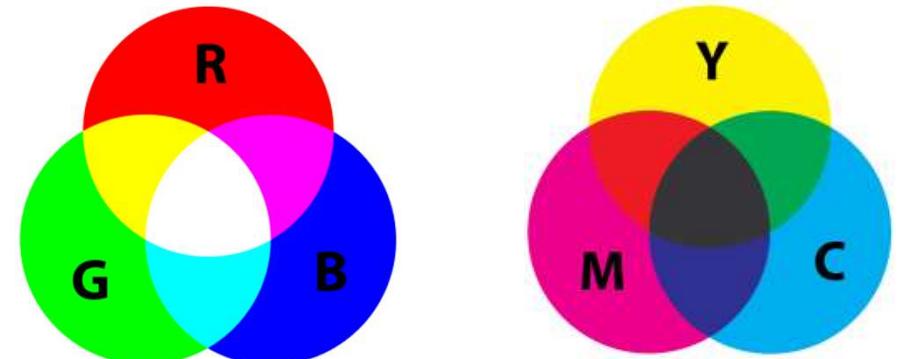
Color Metric Spaces

- CIE XYZ
 - Detect metamers
- CIE L*a*b*
 - Perceptually uniform
- Colorimetry



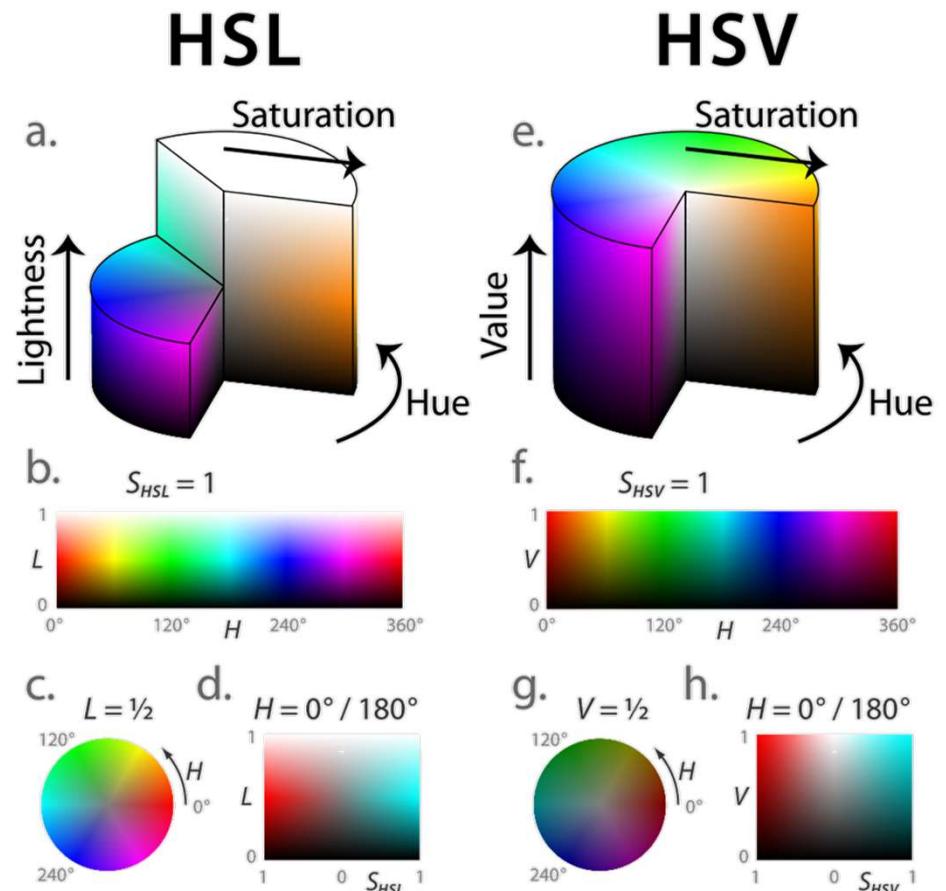
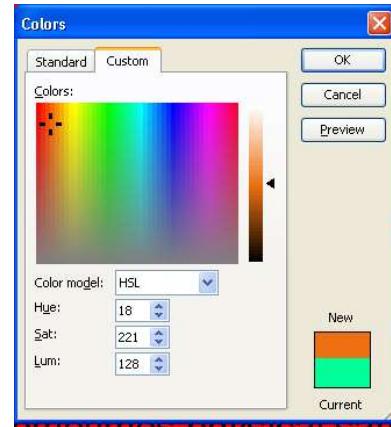
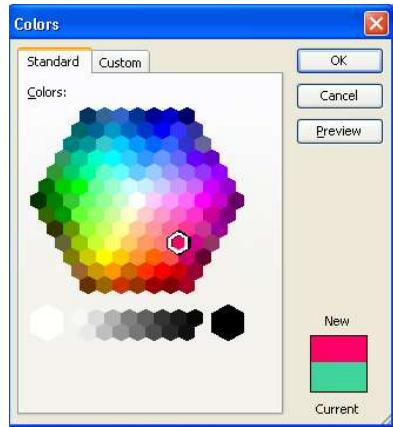
Device Color Spaces

- RGB, CMY(K)
- Additive or subtractive
- Device/paper specific



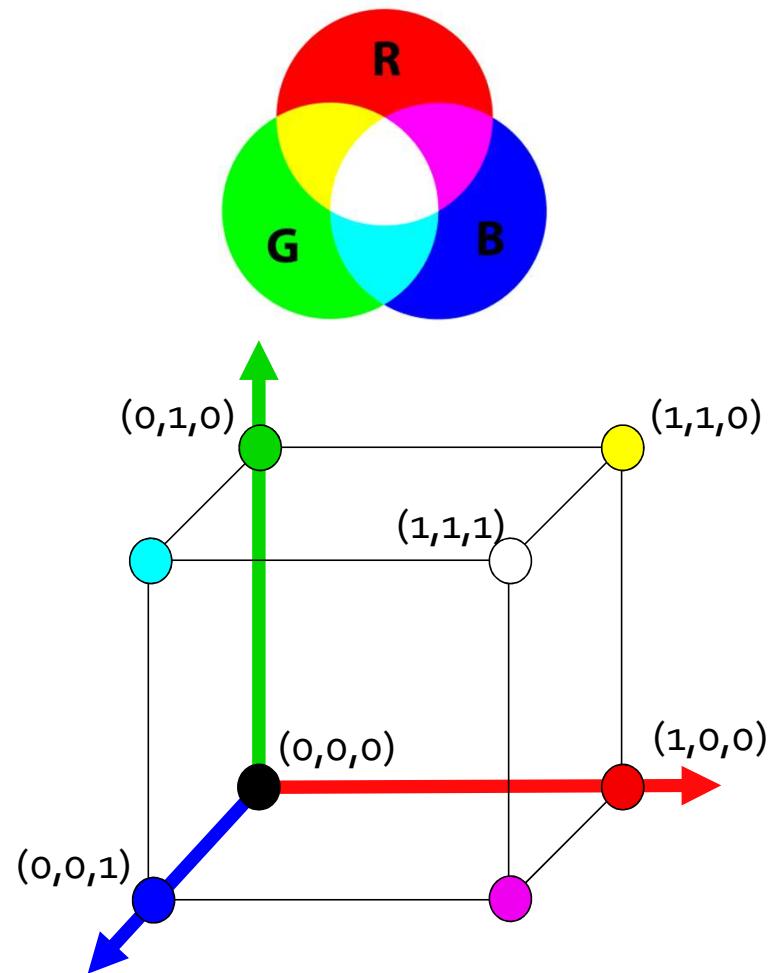
Color Ordering Spaces

- HSV, HLS
- Enable user to intuitively choose colour values according to certain criteria



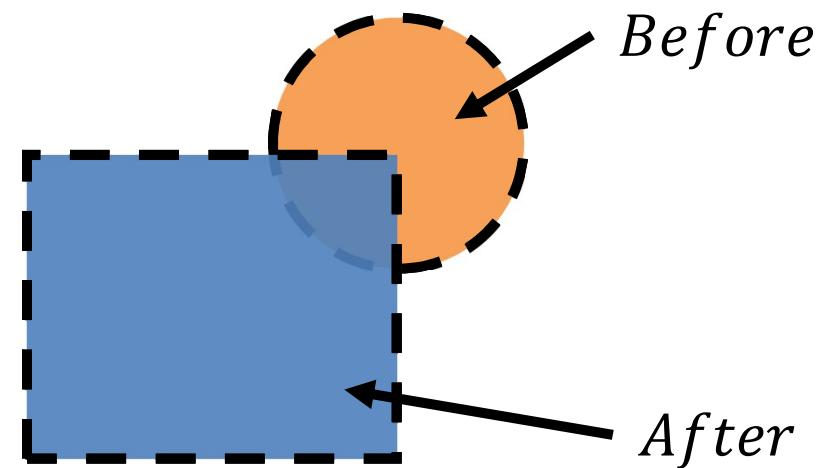
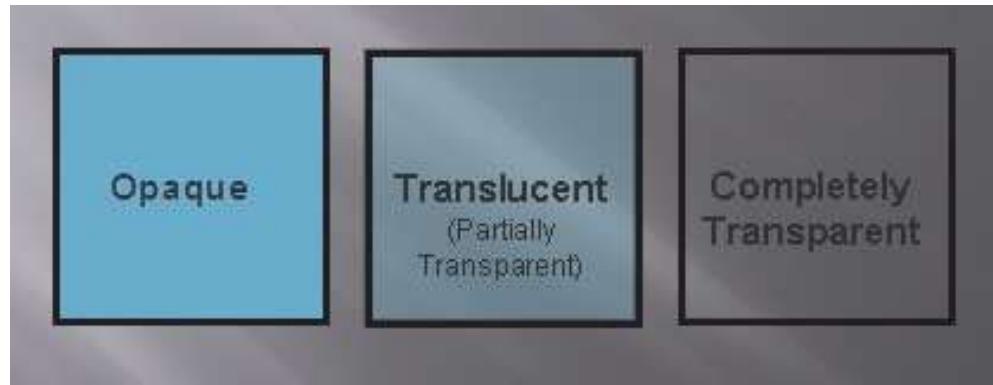
RGB Color Space

- Based on tristimulus theory
- Standardised version – sRGB
- Additive color model (monitors)
- $0 \leq RGB \leq 1$
- Channels independent
 - Calculations / channel

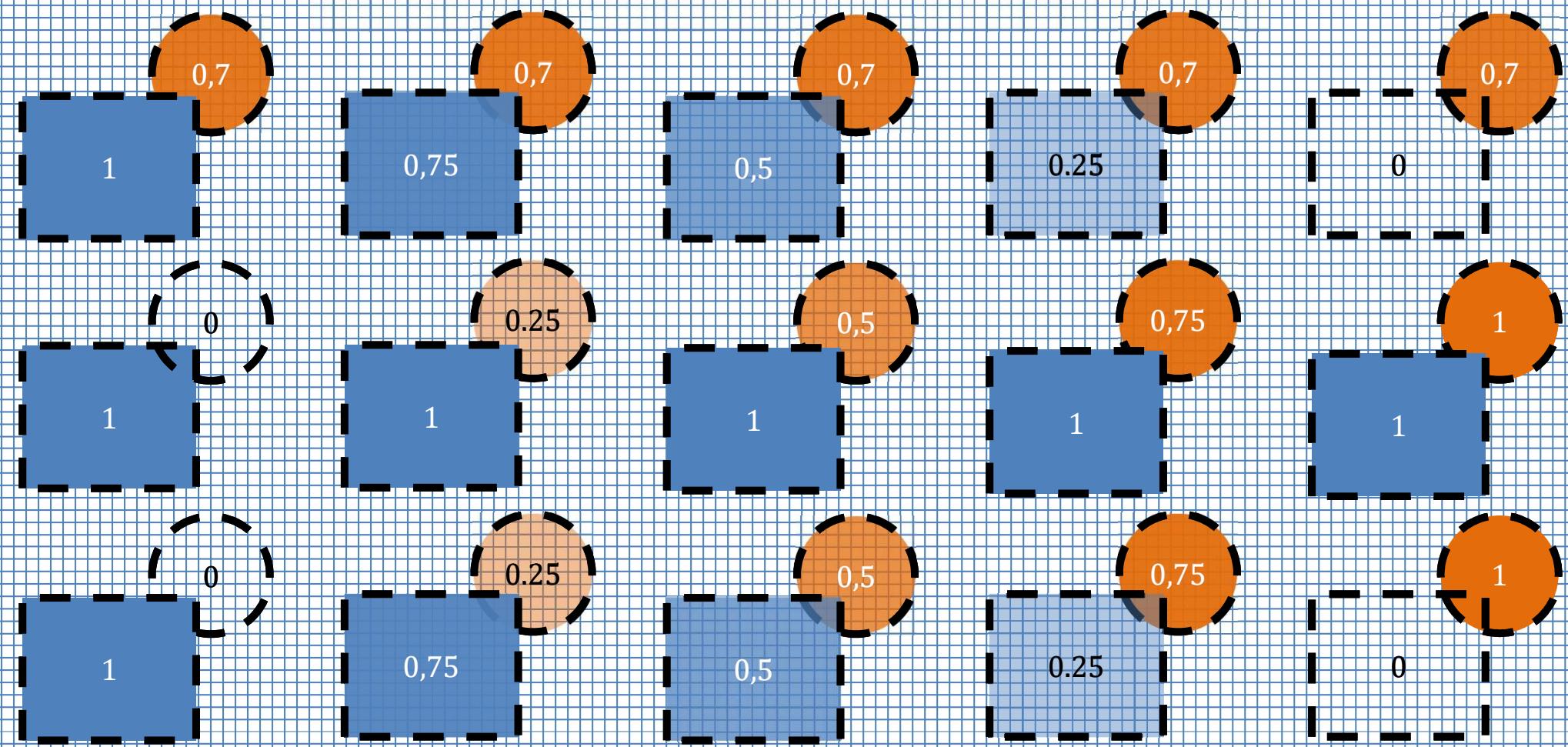


RGBA Color Space

- Extension of RGB with extra alpha channel information
- Alpha channel stores opacity information
 - Alpha = e.x: background shows through; like glass, ...
 - Alpha = 0: transparent
 - Alpha = 1: opaque



Transparency – Varying Alpha

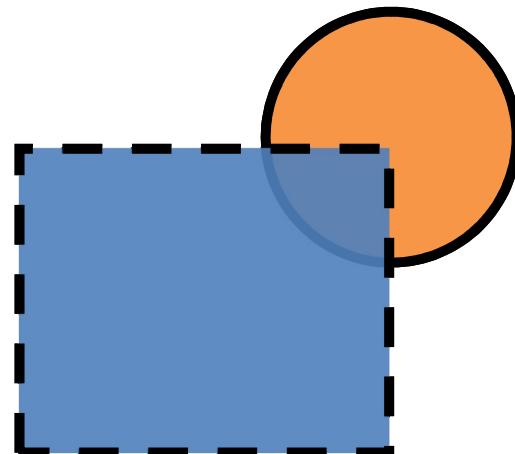


Transparency – Varying Alpha

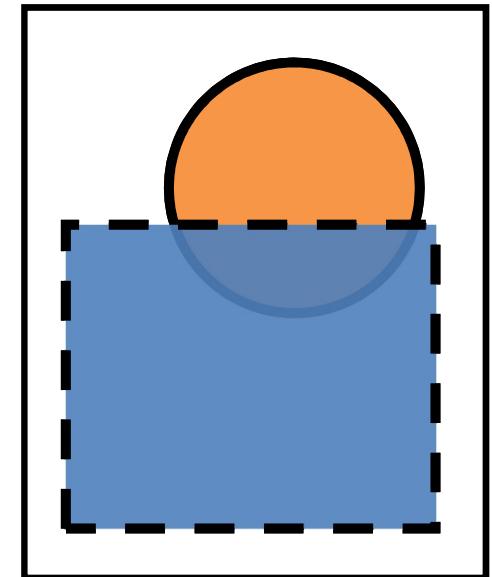
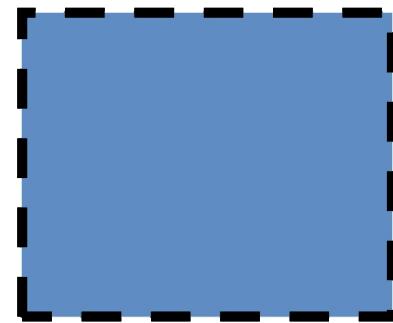
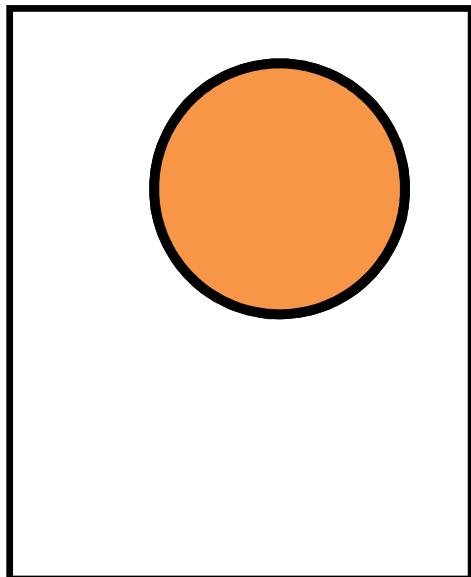
- Three object colors are combined here
 - Background
 - Circle
 - Rectangle
- Order is important
- Let's simplify to understand

Transparency

- We draw a circle
- Then we draw a semi transparent rectangle
 - Resulting color combines what was drawn before with new (rectangle)
 - Resulting color depends on rectangle alpha



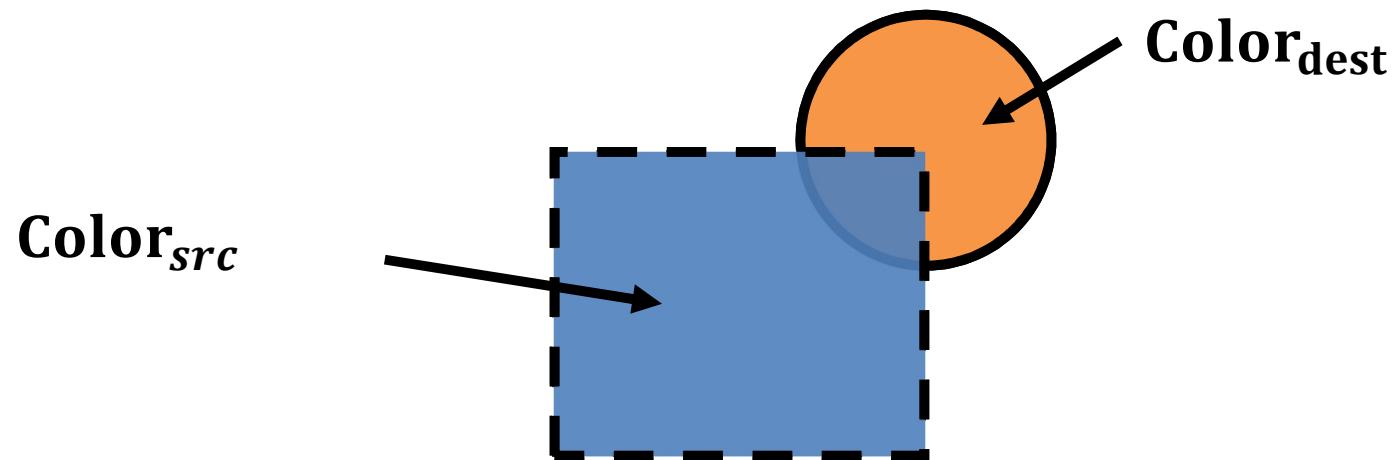
Transparency – Formula



$$\text{Color}_{\text{circle}} * (1 - \alpha) + \text{Color}_{\text{rectangle}} * \alpha = \text{Color}_{\text{out}}$$

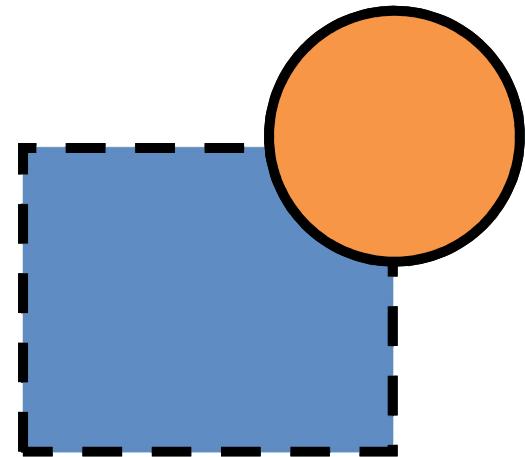
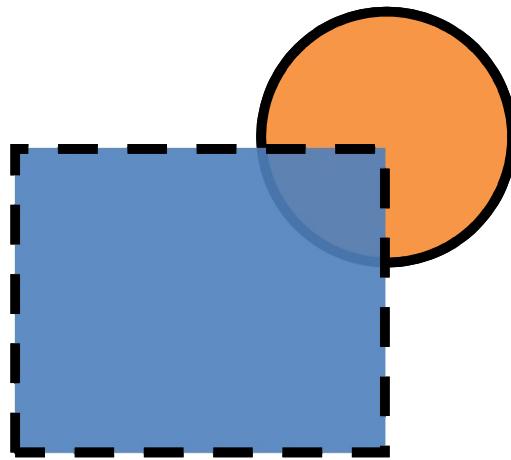
Transparency – Formula (OpenGL Naming)

$$\mathbf{Color}_{out} = \mathbf{Color}_{dest} * (1 - alpha_{src}) + \mathbf{Color}_{src} * alpha_{src}$$



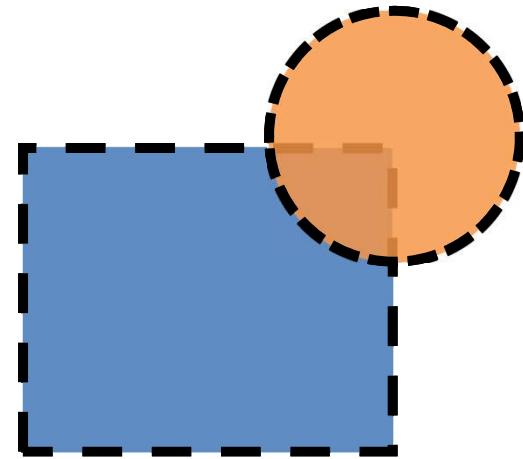
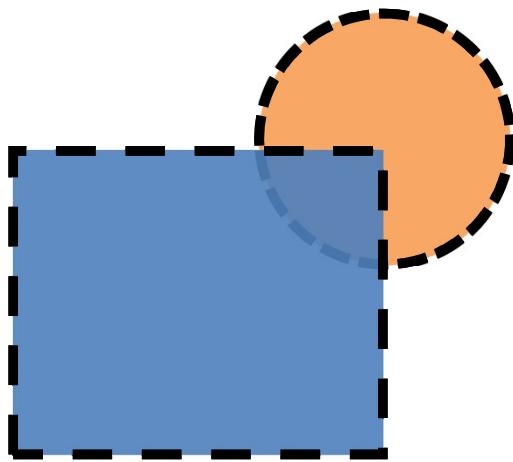
Transparency – Order is Important

- Circle, rectangle
- Rectangle Circle



Transparency – Order is Important

- Circle, rectangle
- Rectangle Circle



RGBA Color space – Alpha Compositing

- More than transparency effect

