# Scientific and Large Data Visualization
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# Visual Perception – Color

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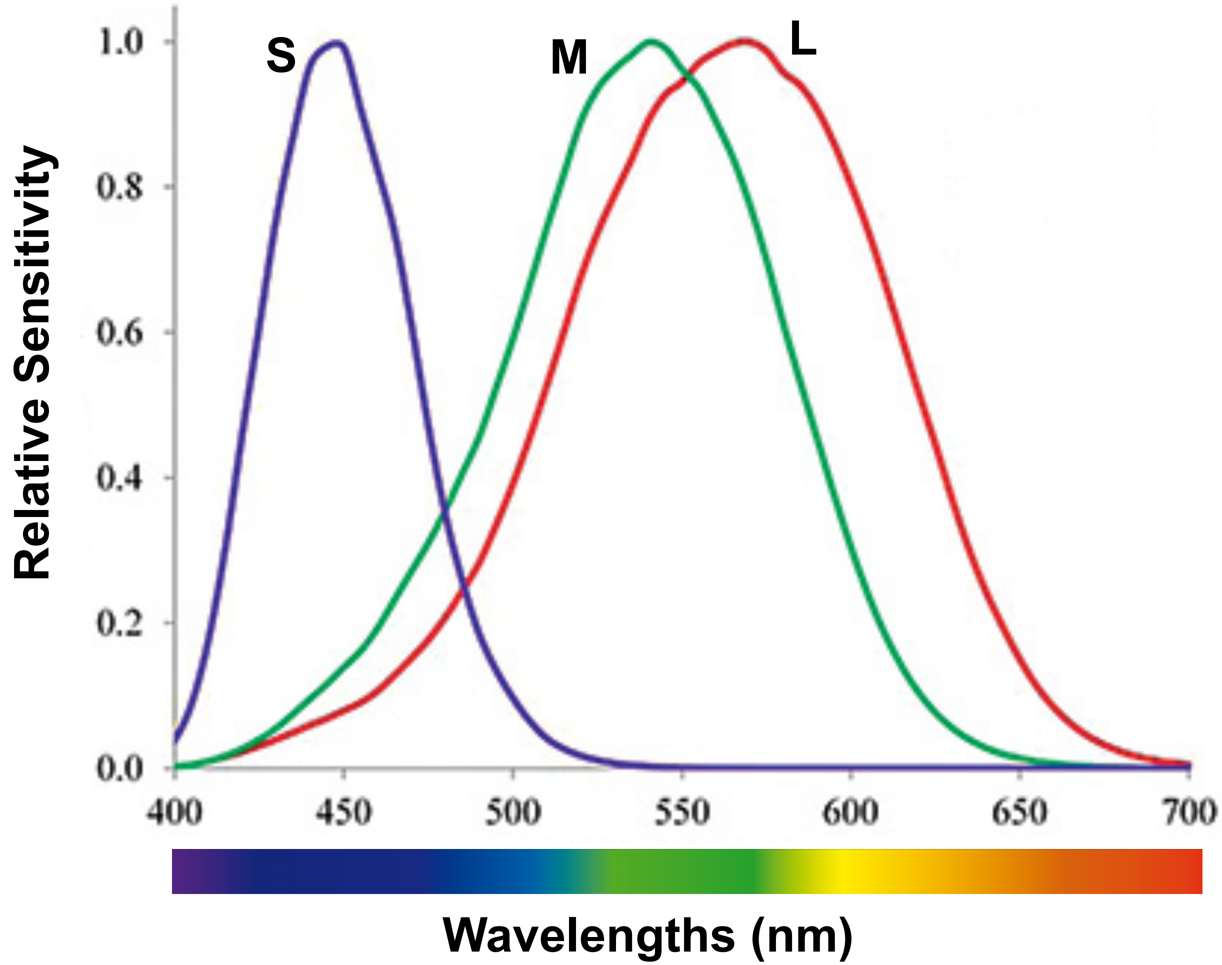
# Overview

- Trichromacy Color Theory
- Opponent Color Theory
- Color Spaces
- Design guidelines

# Trichromacy Color Theory

- We have three types of color photoreceptors (Short cones, Medium cones, and Long cones).

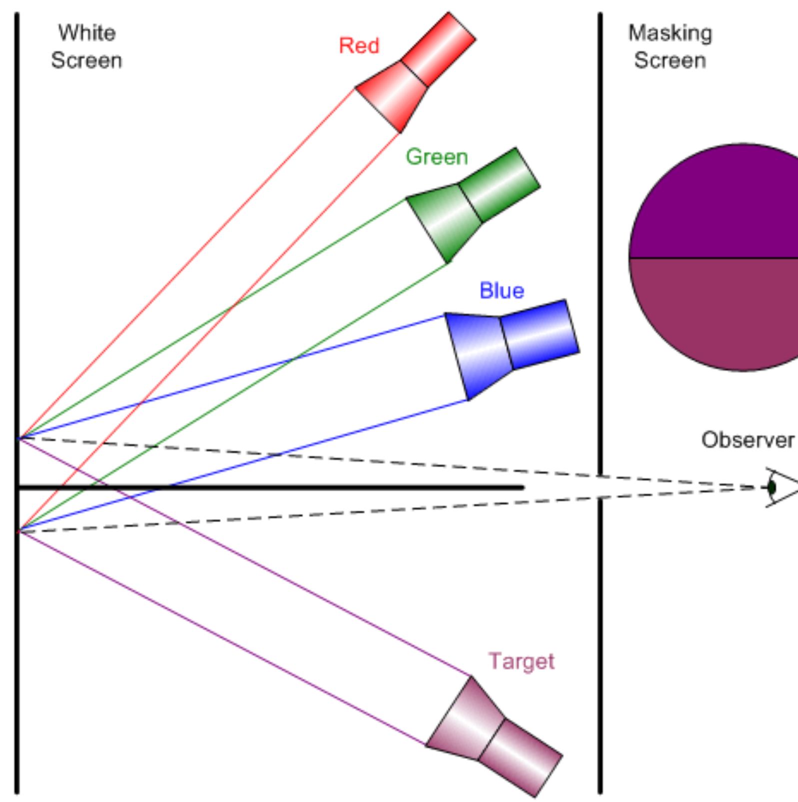


# Color Space

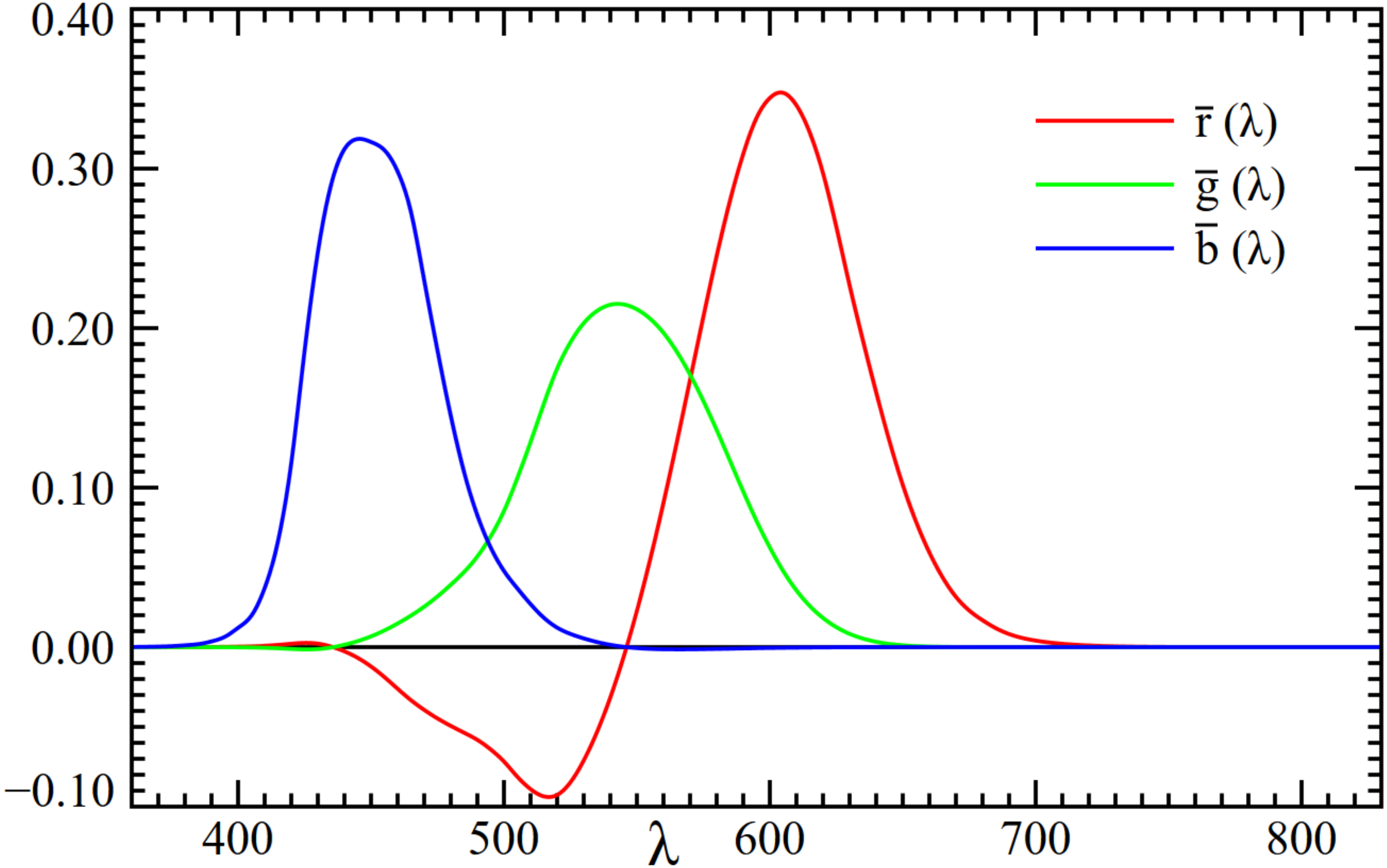
- Different primaries define different color spaces.
- Different color spaces have different purposes.
- Some color spaces: CIE RGB, CIE XYZ, CIE LAB, HSL, HSV, etc.

# CIE RGB Color Space

- CIE stands for *Commission Internationale de l'Eclairage* (founded in 1912).
- CIE defined the "mean" human response of a color stimulus (*standard observer*).



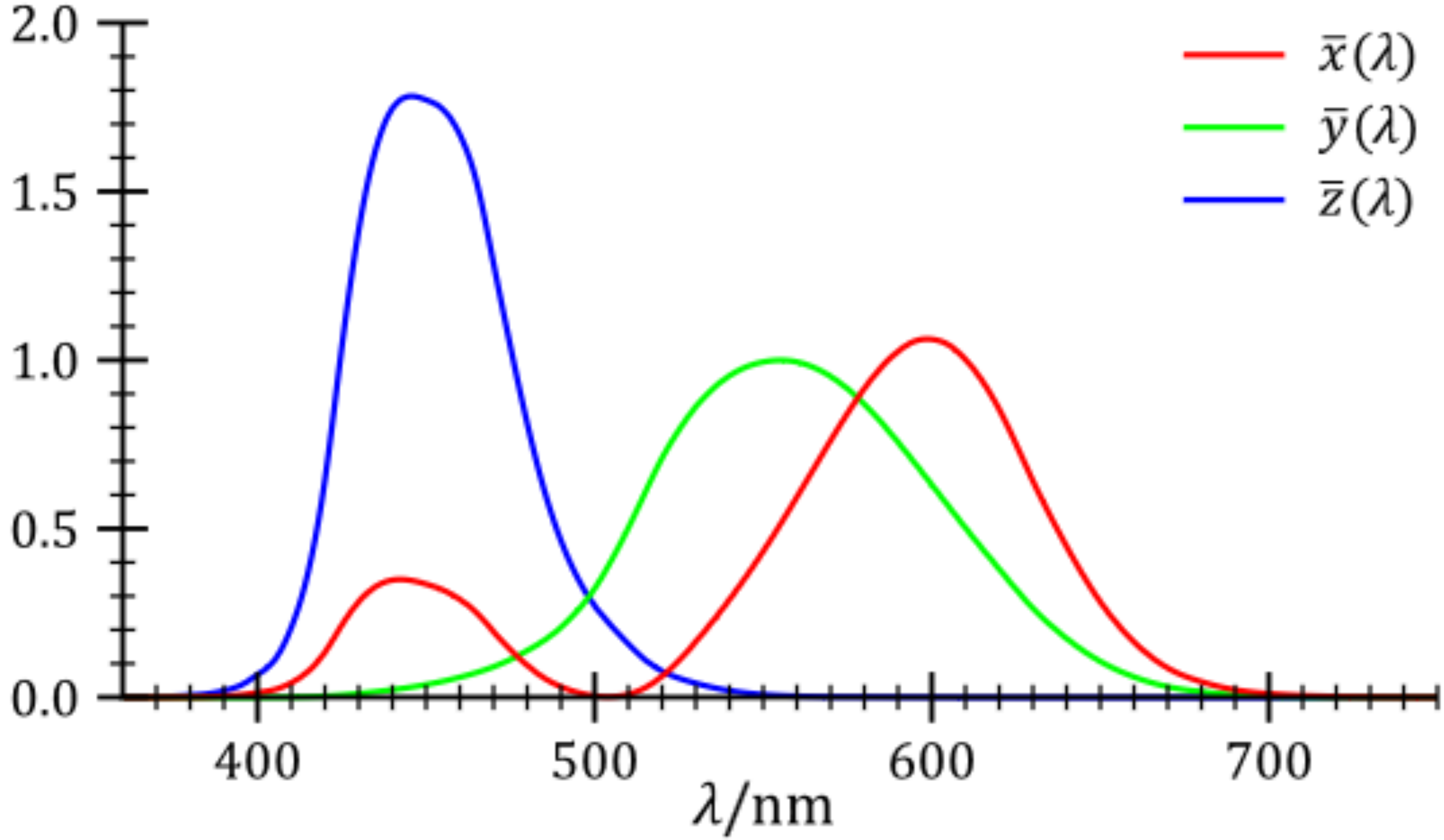
# CIE RGB Color Matching Function



# CIE XYZ Color Space

- A transformed version of the CIE RGB color matching functions such that:
  - *Y* corresponds to the perceived luminance in well-lit conditions.
  - *Z* is close to the short cone response.
  - *X* is a mix such that the values become non-negatives.
- For a fixed value of Y, the plane XZ contains all the possible chromaticities at that luminance.

# CIE XYZ Color Matching Functions



# CIE xyY Color Space

- It is a normalized color space.

**Chromaticity Coordinates**

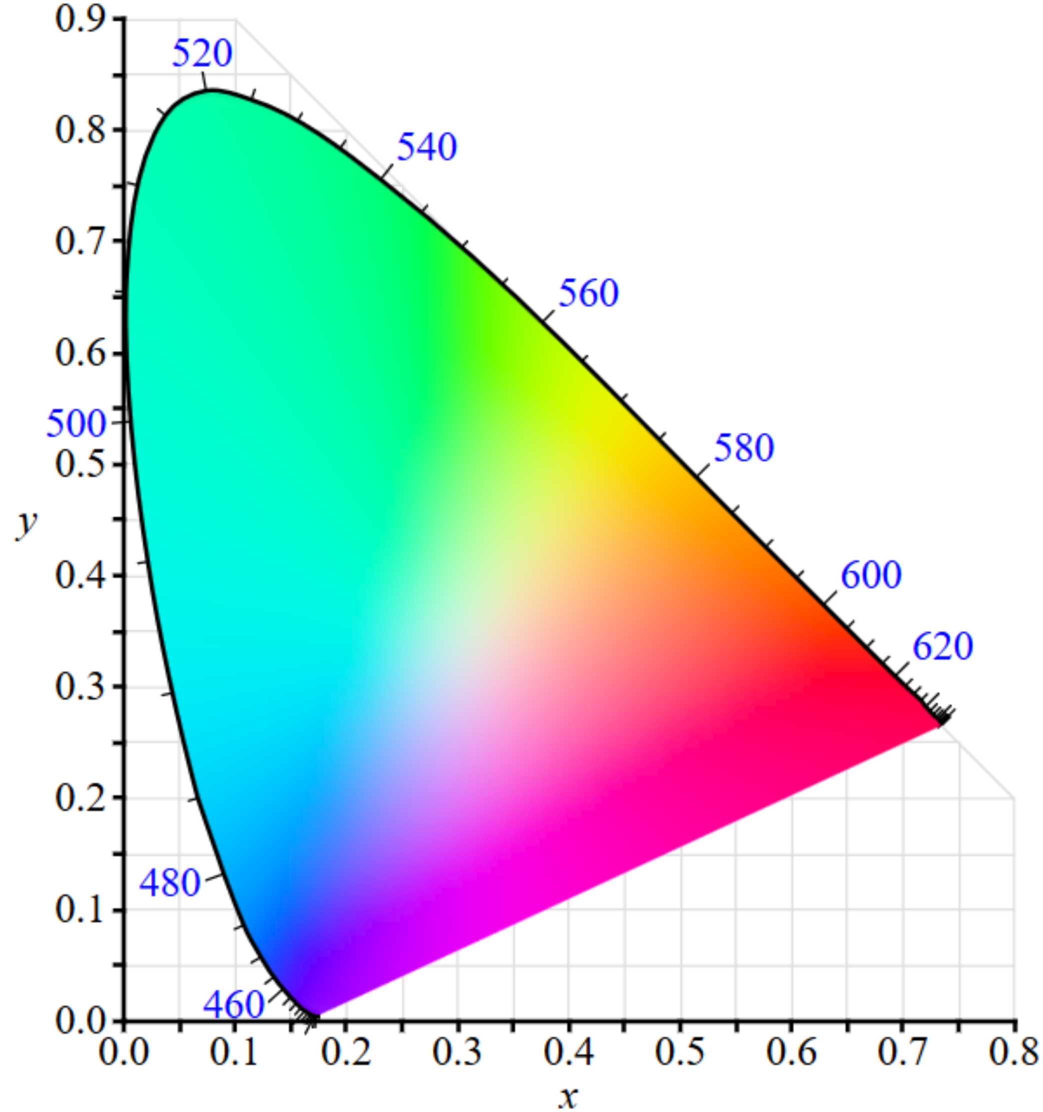
$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

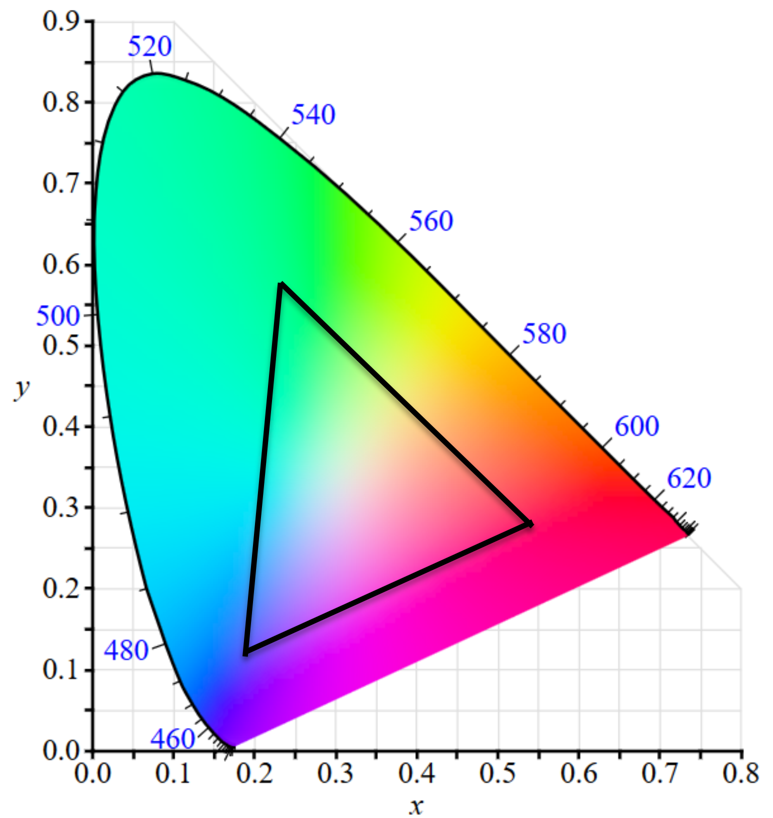
- Given *x*, *y* and *Y* we can came back to CIE XYZ.

# Chromaticity Diagram



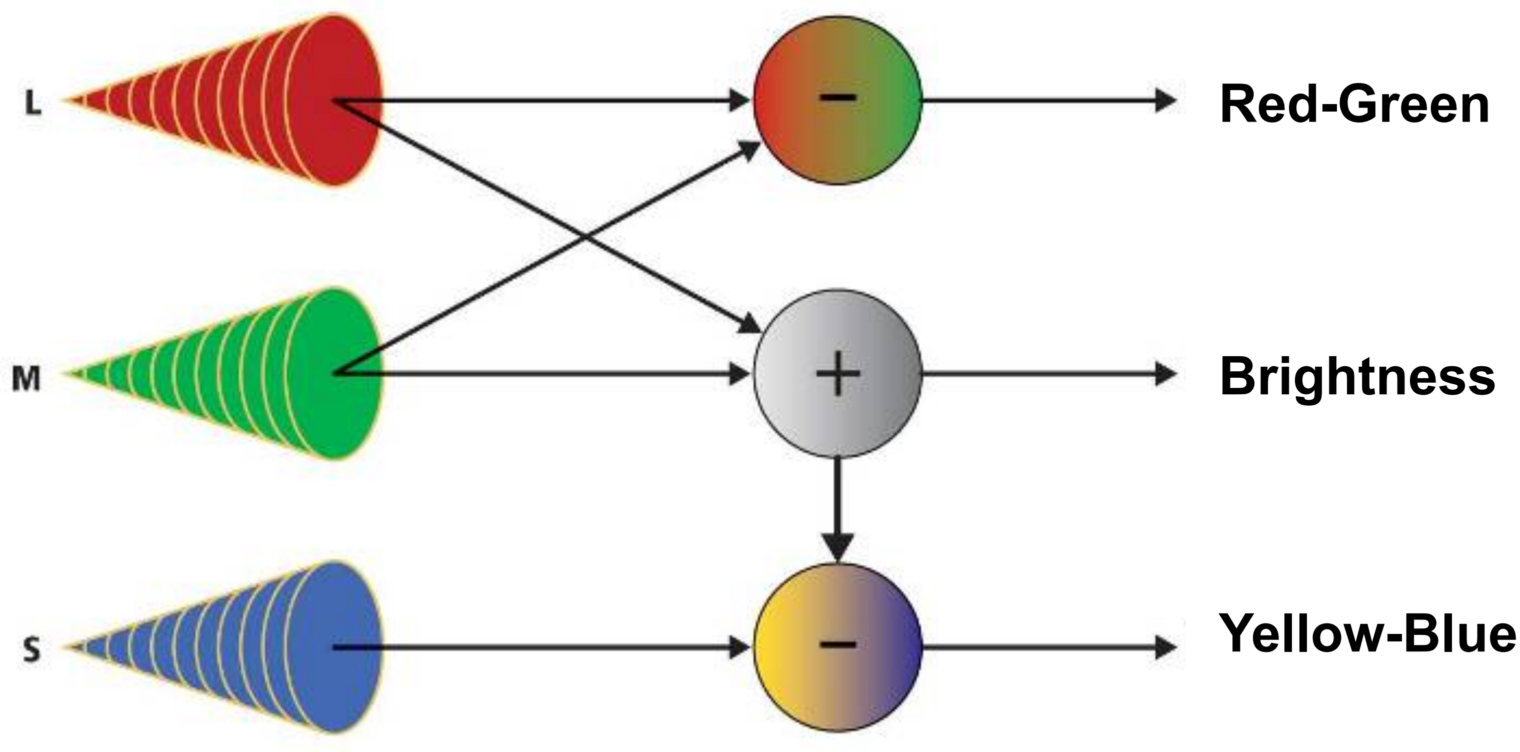
# Gamut

- The colors that a device (a printer, a monitor) can reproduce.



# Opponent Color Theory

- Cones combines their stimulus forming three pairs of colors that compete together to form the final one. (Hering, 1920)



# Opponent Color Theory

- Evidence that supports the theory:
  - Naming
  - Unique hues
  - Neurophysiology
- Properties of opponent color channels:
  - Spatial resolution
  - Shape perception
  - Color contrast


NORMAL VISION
DEUTERANOMALY
PROTANOPIA
TRITANOPIA

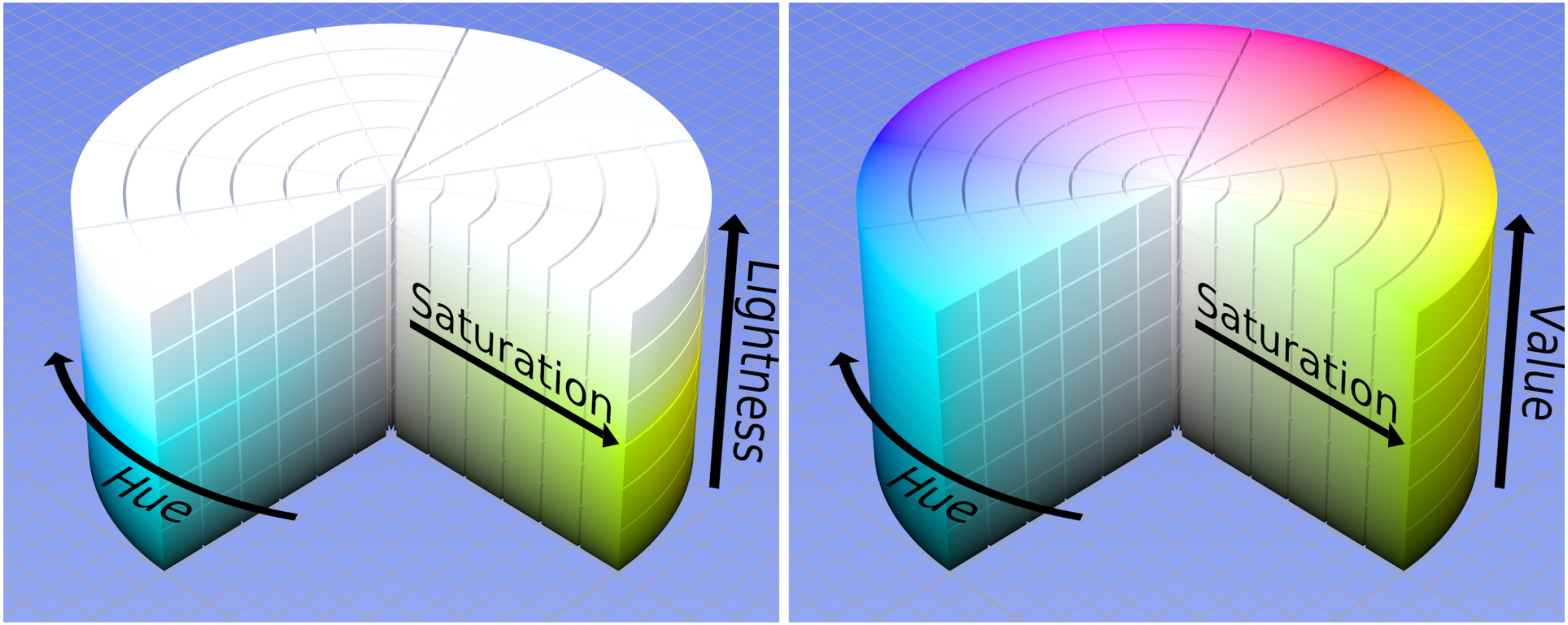
# Color Theories

- Trichromacity Theory and Opponent Color Theory work at different levels.
- Trichromacy Theory explains what happen at level of photoreceptors.
- Opponent Color Theory explains what happen at neural level.

# HSL and HSV Color Space

- **HSL** stands for **H**ue, **S**aturation and **L**ightness:
  - Hue controls the chroma.
  - Lightness is related to the luminance.
  - Saturation controls the purity of the color (color intensity).
- **HSV** stands for **H**ue, **S**aturation and **V**alue:
  - **V** is related to the luminance.

# HSL and HSV Color Space



# CIELAB

- *CIELAB* is a perceptually uniform color space.
- *L** is the component related to the luminance (0=black, 100=white).
- *a** and *b** represent the chromaticity:
  - *a** is the green-magenta opponent.
  - *b** is the blue-yellow opponent.

# Color Differences

- The difference between two colors can be evaluated using the Euclidean distance.
- Not so meaningful for RGB color space.
- Meaningful from a perceptual point of view for CIE LAB color space.

# Color Differences

- *Delta E (1976)* is defined as:

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

- $\Delta E < 1$ : Not perceptible.
- $1 < \Delta E < 2$ : close observation is needed to perceive the difference.
- $2 < \Delta E < 10$ : different but similar color.
- Not perceptually uniform as originally intended → superseded by $\Delta E^*_{94}$ (1994) and $\Delta E^*_{00}$ (2000).

# Luminance and Visualization

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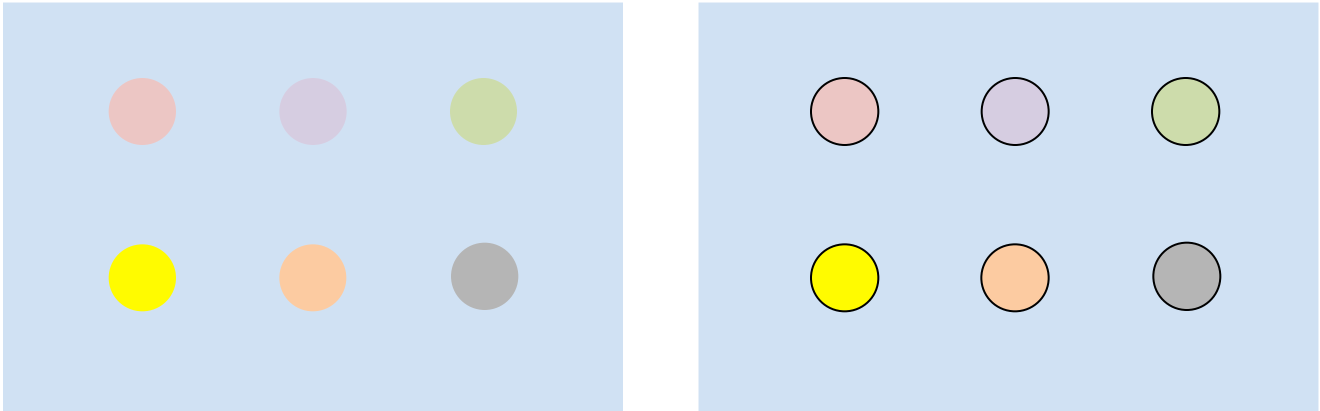
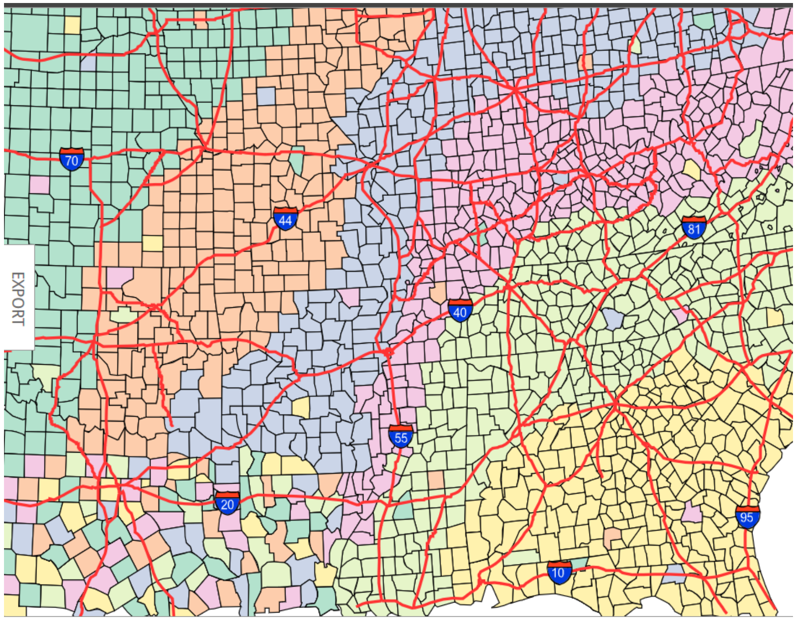
# Luminance and Visualization

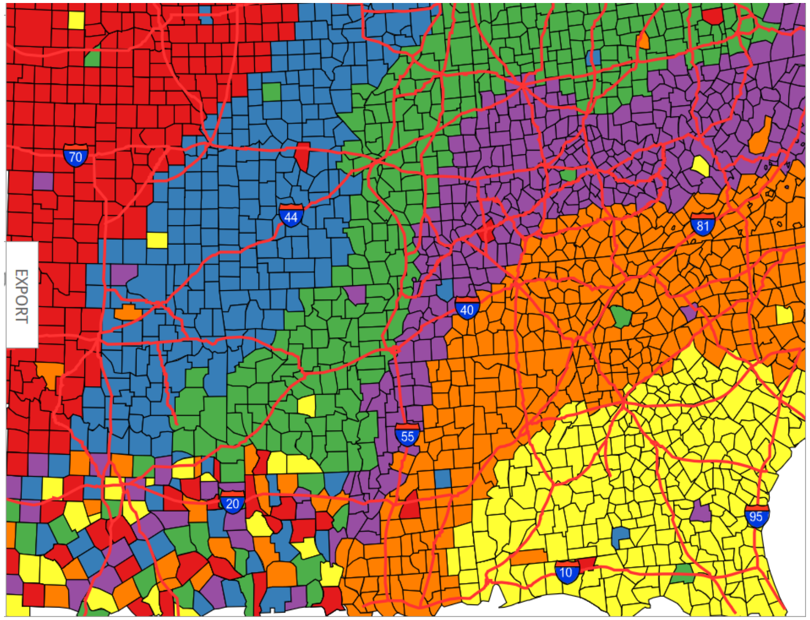
- Adequate luminance contrast is required even if colors with different chromaticity are used.
- To improve the readability of colored symbols a luminance contrast boundary can be added.



# Saturation and Visualization

- Use saturated for color coding of small symbols/fine details, and less saturated colors for coding large areas.




**From ColorBrewer2 – Color Advice for Cartography ([http://colorbrewer2.org](http://colorbrewer2.org)).**

# Color and Categories

- Post and Green (1986) carried out an experiment on the naming of colors (210 different colors were shown on a black background in a darkened room).
- Only eight colors plus white are consistently named.
- Not generally applicable but this fact suggest that only few colors can be used as category labels.

# Color and Text

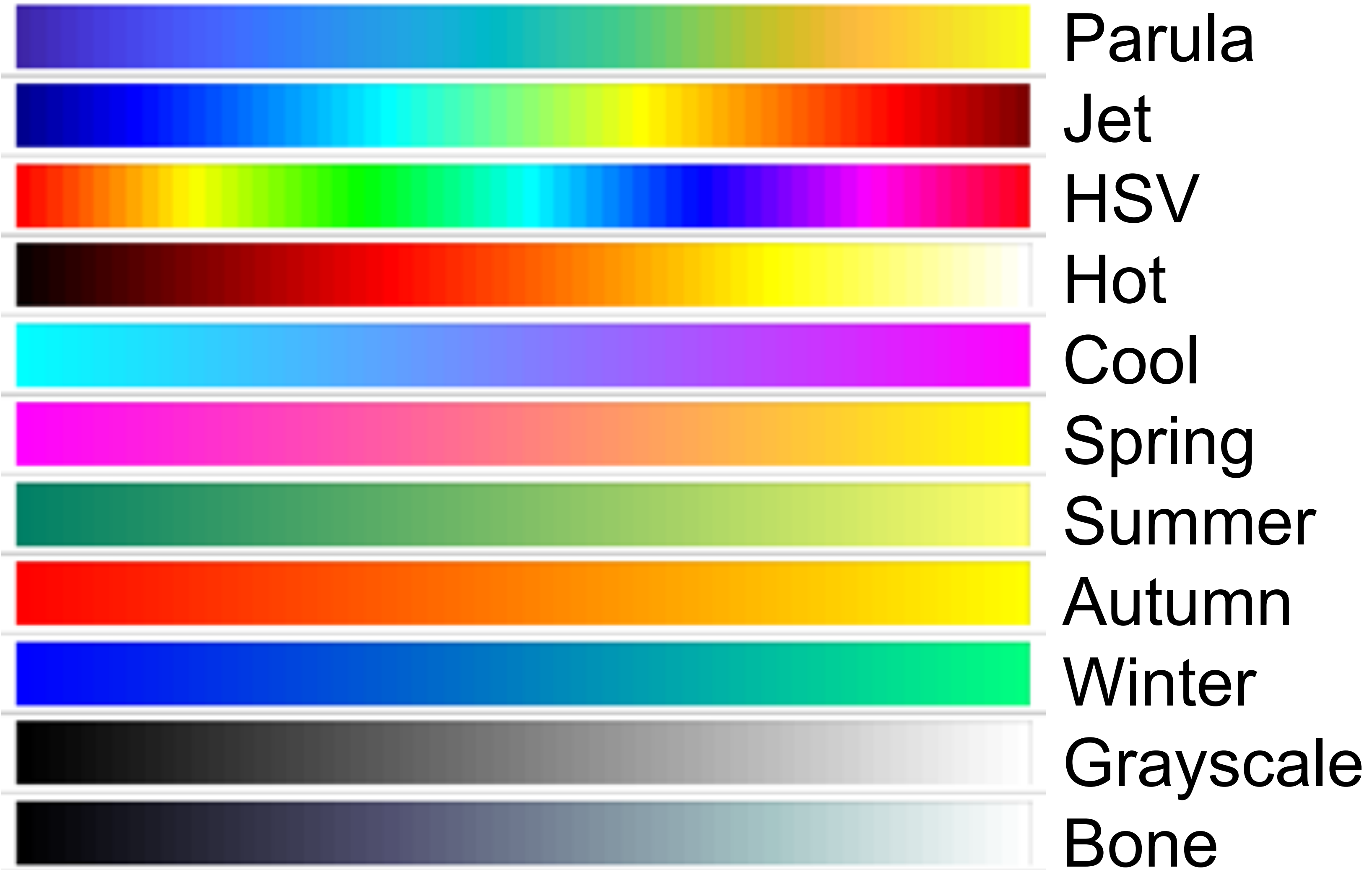
- To highlight text with different colors ensuring to maintain a good luminance contrast with the background.
- Code example:

```
# Define the test inputs
test_input_fn = tf.estimator.inputs.numpy_input_fn(
    x={"x": np.array(test_set.data)},
    y=np.array(test_set.target),
    num_epochs=1,
    shuffle=False)

# Evaluate accuracy.
accuracy_score = classifier.evaluate(input_fn=test_input_fn)["accuracy"]

print("\nTest Accuracy: {0:f}\n".format(accuracy_score))
```

# Color Ramps




**Matlab pre-defined color ramps.**

# Color Ramps

- Avoid color ramps problematic for color-blindness people.
- Use spectrum-based color ramp when its use is deeply embedded in the culture of the users.
- To reveal fine details use pseudocolor sequences that varying in luminance, not only in chromaticity.

# Summary

- Color is not so important for our life but color is very important for visualization.
- Two color theories have been developed and co-exists.
- The use of color needs to pay attention on several details.

# Questions ?