Data Visualisation

CMP020L013A

Week 7: Colour Theory and Models

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Agenda

- Colour theories
- Colour vision and human eye
- Color modeles, scales
- Colour Blindness

Use Case for Colour

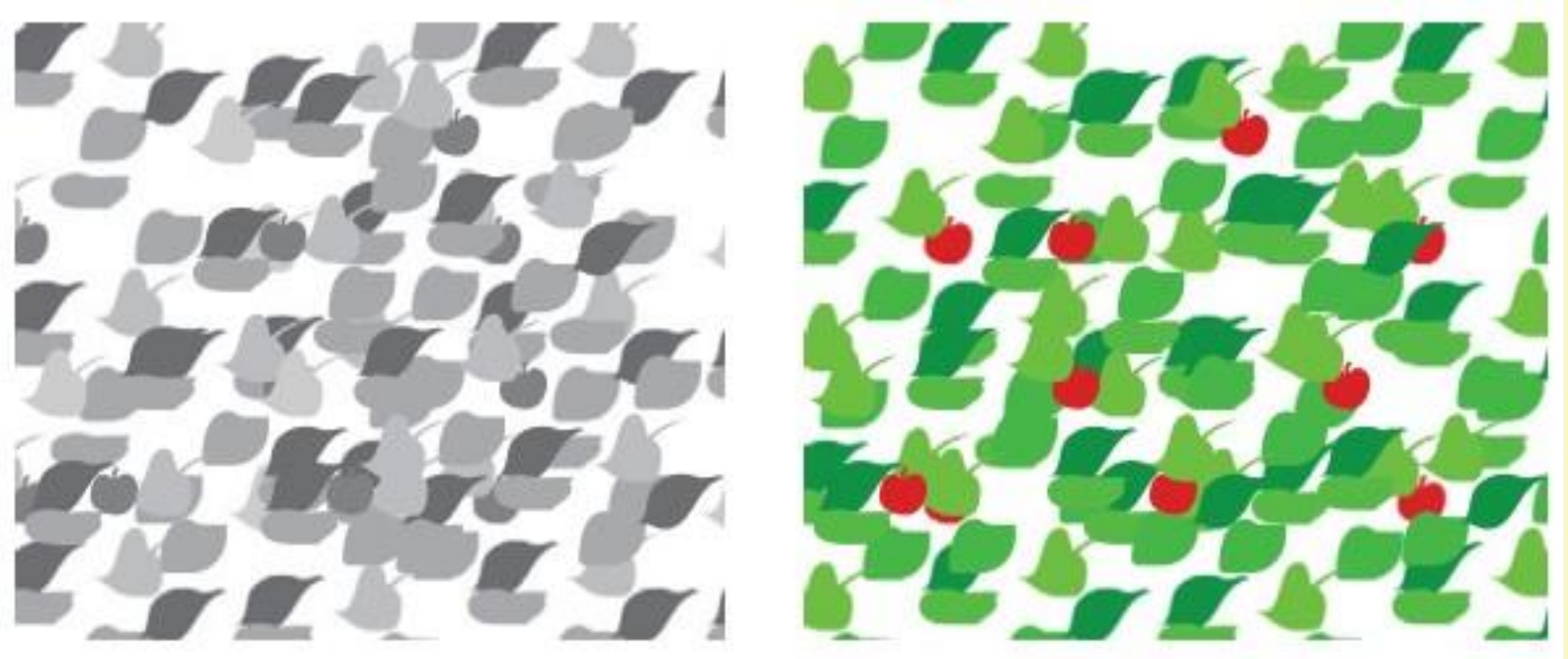
- There are three fundamental use cases for colour in data visualisations:

1. to distinguish groups of data from each other,
2. to represent data values,
3. to highlight.

- The types of colours we use and the way in which we use them are quite different for these three cases.

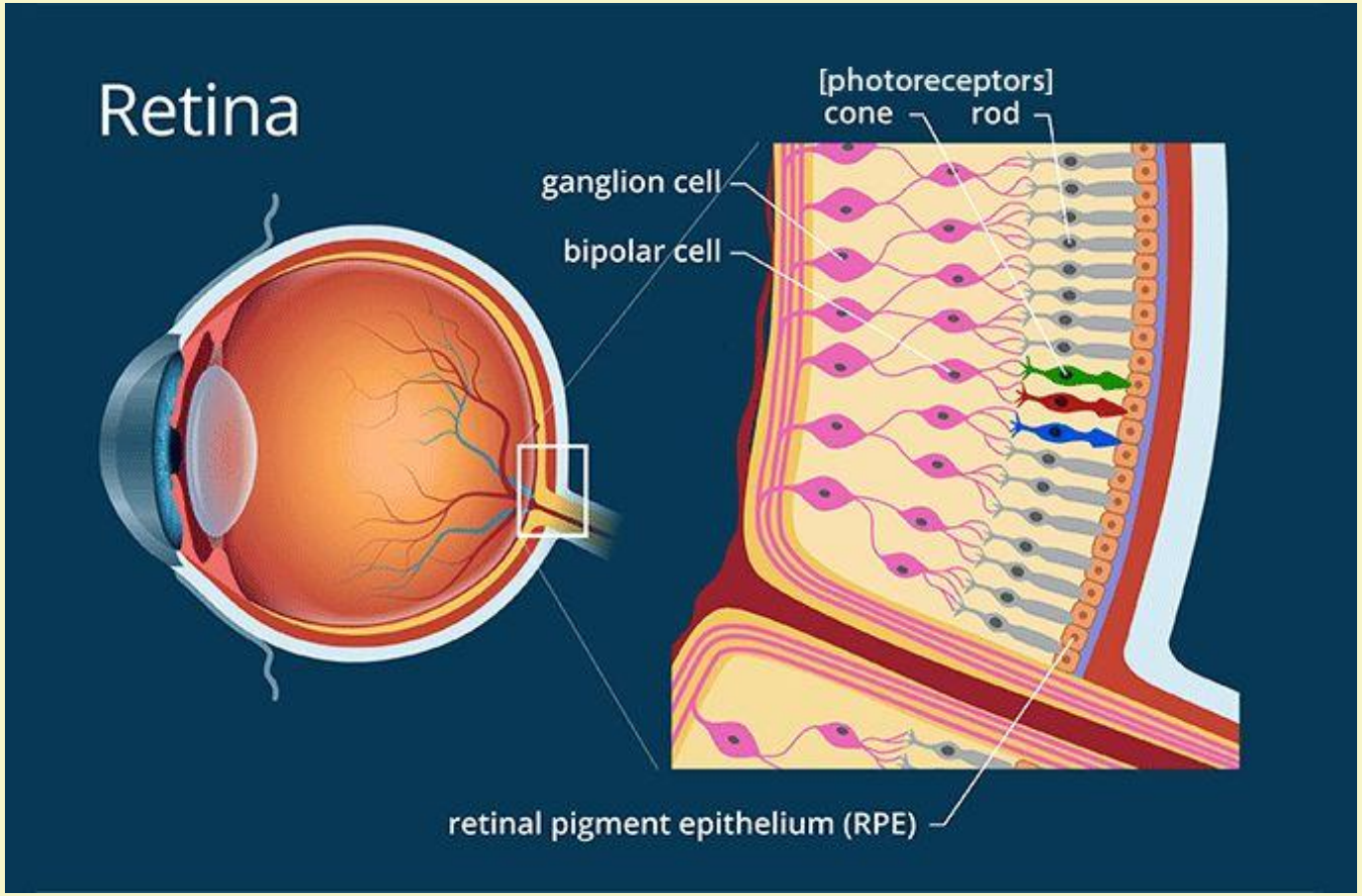
Use Case for Colour

- Finding the cherries is much easier with colour vision



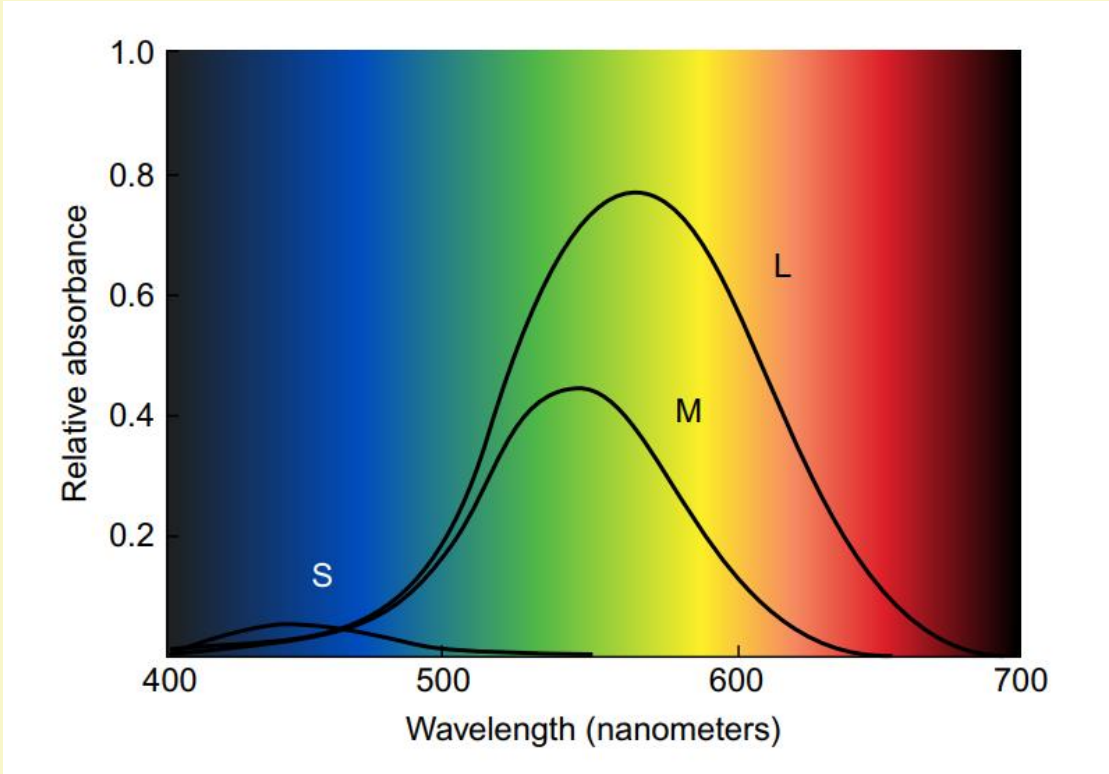
Colour Vision

- The retina of the eye has two different kinds of receptors.
- The rods actively contribute to vision only in low-light settings and provide low-resolution black-and-white information.
- The main sensors in normal lighting conditions are the cones.



Colour Vision

- ThLight of different wavelengths is absorbed by the three different receptor types (S, M, L – wavelength)

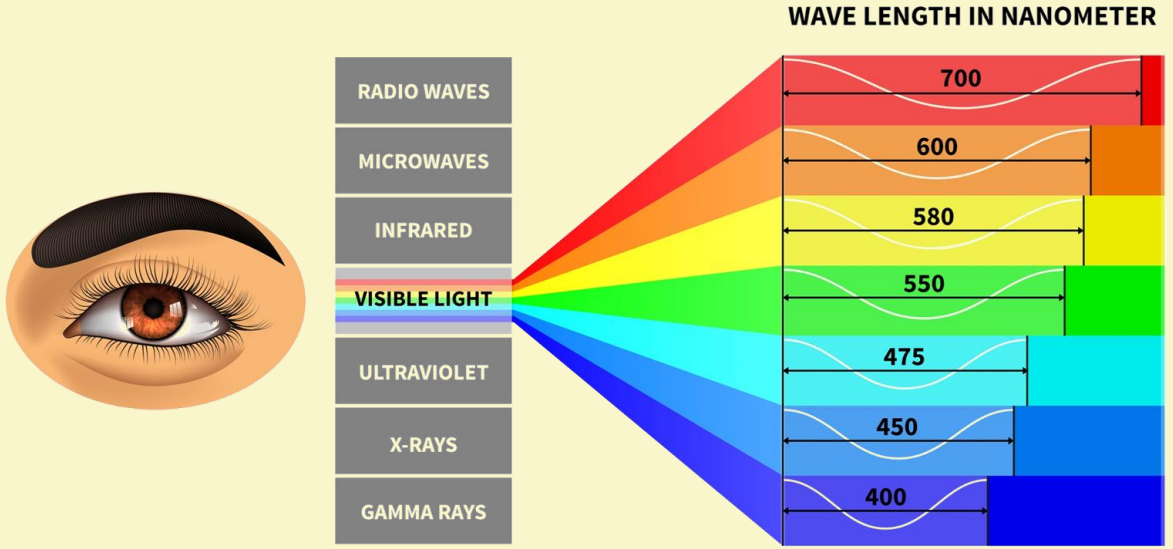


Trichromacy Colour Theory

- Three distinct colour receptors (cones) in retina that are active at normal light levels
- The fact that there are only three receptors is the reason for the basic three-dimensionality of human color vision.
- The term *color space* means an arrangement of colors in a three-dimensional space.

Colour Vision and Colour Models

- Psychological way human cognition formulates coloured imagery based on wavelengths
- Computers use a colour model, a mathematical approximation of the naturally non-quantifiable nature of human visual perception
- A colour model is a structured system for creating a full range of colours from a small set of defined primary colours.

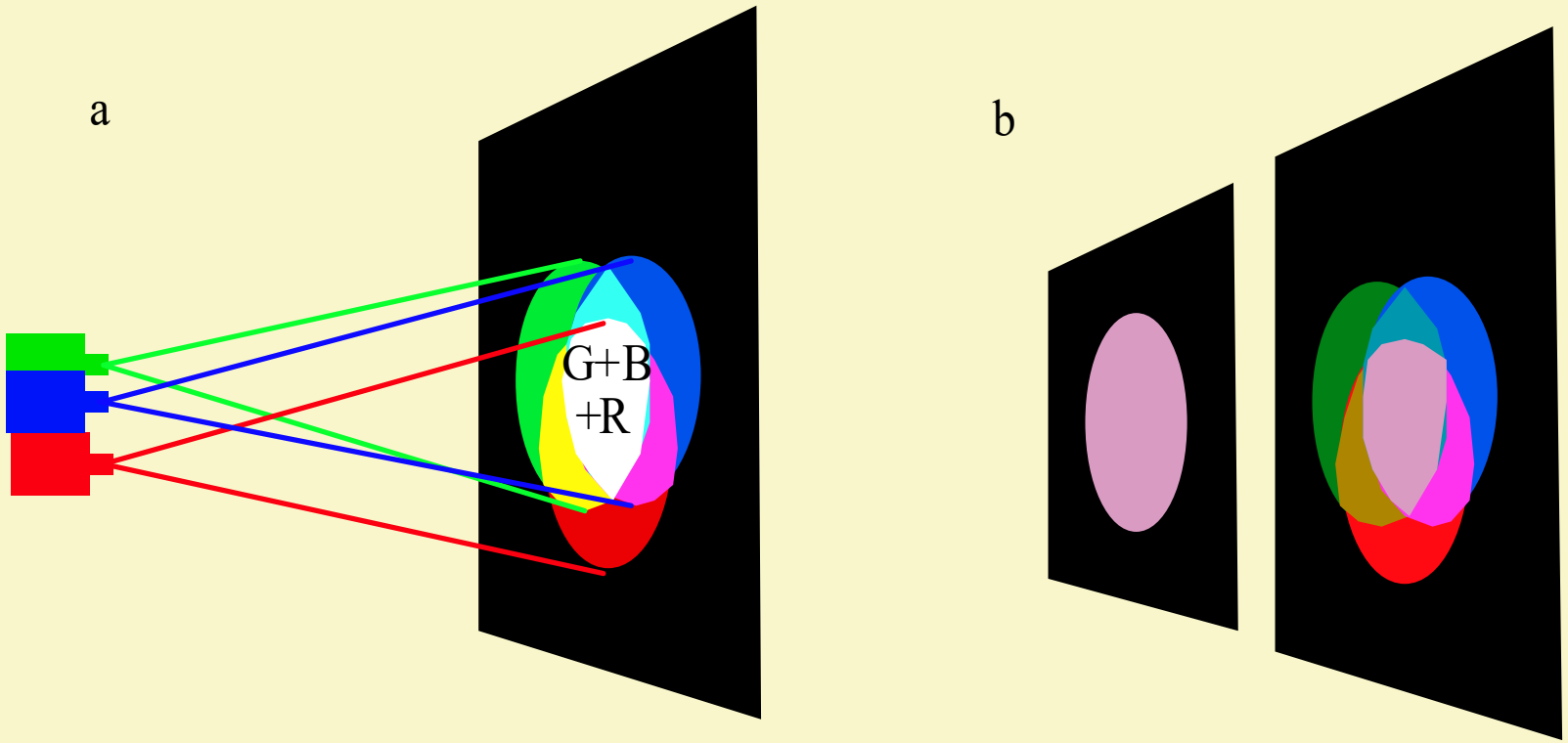


Color Measurement

- Based on the “standard observer”
- Assumes all humans are the same
  - We can match any color with a mixture of no more than three primary lights
  - We can describe a color by the following equation:
  - $C \equiv rR + gG + bB$ (perceptual match)
  - where C is the color to be matched; R, G, and B are the primary light sources to be used to create a match; and r, g, and b represent the amounts of each primary light

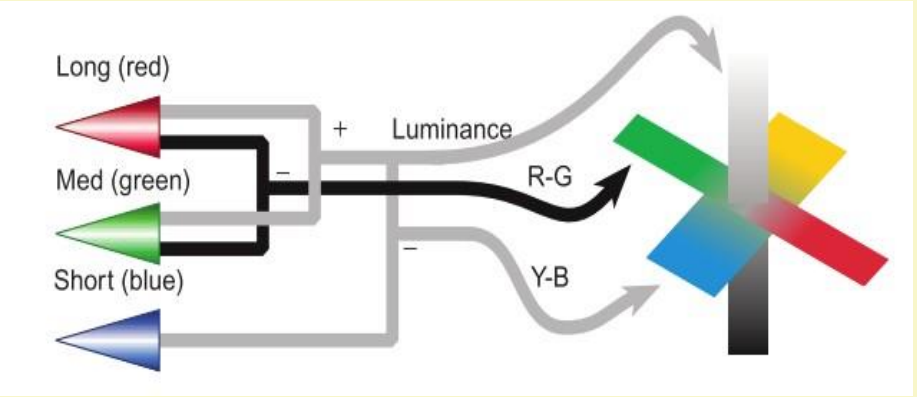
Color Measurement

- C ≡ rR + gG + bB (perceptual match)



Opponent Colour Theory

- Six elementary colours, arranged perceptually as opponent pairs along three axes
  - black–white
  - red–green
  - yellow–blue



- Opponent colour theory predicts that certain colour names should not occur in combination.
- We often describe colours using combinations of colour terms, such as yellowish green or greenish blue.
- The theory predicts that people will never use reddish green or yellowish blue, because these colours are polar opposites in the opponent colour theory

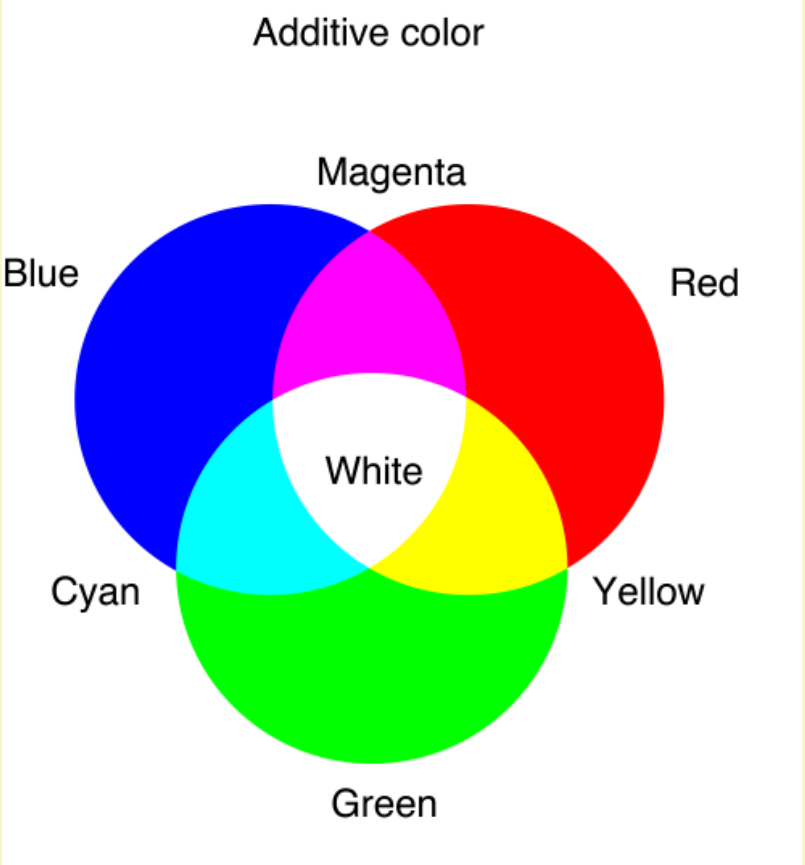
Colour Models

- The most commonly used color models:
  1. RGB (RED — GREEN — BLUE)
  2. CMY and CMYK (CYAN — MAGENTA — YELLOW)
  3. HSI (HUE — SATURATION — INTENSITY)

Colour Models

Additive Colours

- These models use the light emitted directly from a source to display colours
- These models mix the different amount of RED, GREEN(G), and BLUE(B) (RGB primary colors) light to produce rest of the colors.
- Adding the RGB primary colors produces WHITE image.
- Example: RGB model is used for digital displays such as laptops, TVs, tablets, etc.



Colour Models

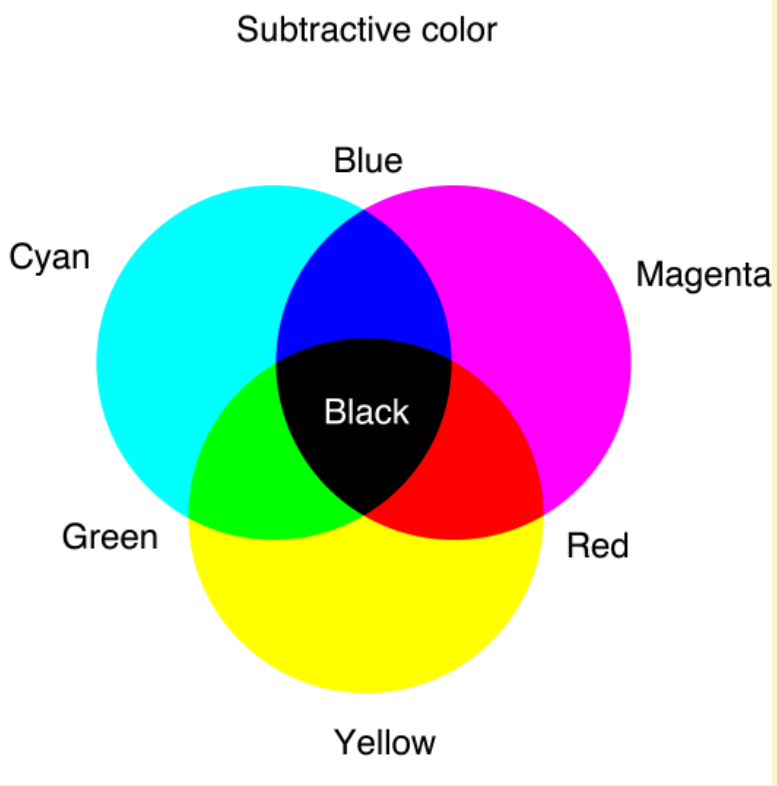
RGB colour model

- It is an additive colour model in which red, green, and blue are added together in various ways to reproduce a wide range of colours
- A pixel is represented using 8 bits for each Red, Green, and Blue.
- This creates a total of around 16.7 million colours (2^{24}).
- Equal values of these three primary colors represent shade of gray color ranging from black to white
- From RGB mix we can generate secondary colours (Yellow, Cyan, and Magenta)

Colour Models

Subtractive Colours

- These models use printing inks to display colors.
- Subtractive colour starts with an object that reflects light and uses colourants to subtract portions of the white light illuminating an object to produce other colours.
- If an object reflects all the white light back to the viewer, it appears white, and if it absorbs all the light then it appears black.
- Example: Graphic designers used the CMYK model for printing purposes.



Colour Models

CMYK colour model

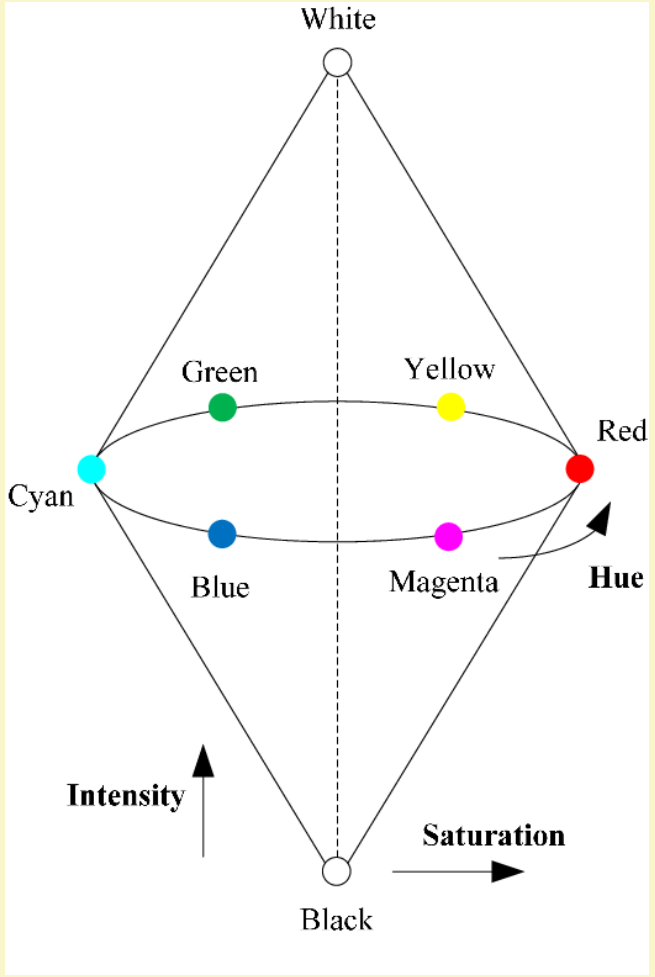
- Colour pigments reduce the reflection of the original white light.
- Historically, for colour printing processes to work, individual plates were created for the Cyan, Magenta, and Yellow (CMY) colour pigments.
- The plates were registered over top of each other to produce full-color images and the process was called a three-color printing process.
- Later, the colour printing process was modified to allow for a Black plate to support the printing of Black text and other Black elements, with the CMY printing plates being registered or “Keyed” against the Black plate.

Colour Models

HSI colour model

- RGB is not a particularly intuitive way to describe colors.
- HSI stands for Hue, Saturation, and Intensity.
- RGB is better for colour generation, but HSI is better for colour description
- When humans view a color object, its hue, saturation, and brightness are described.

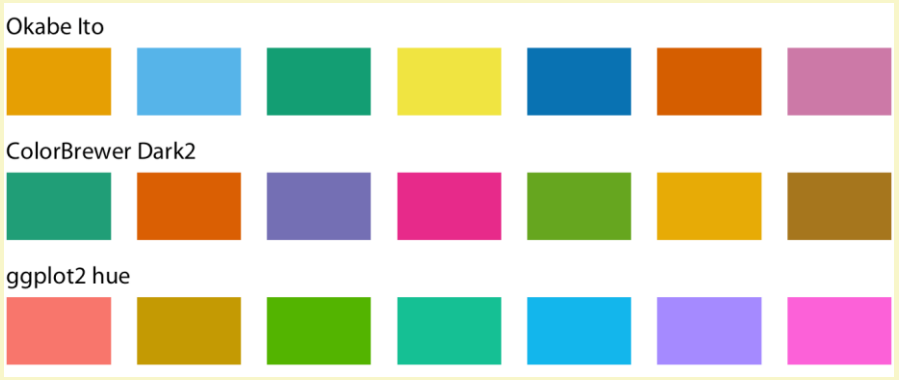
1. **Hue**: It describes a pure colour.
2. **Saturation**: It measures the extent to which a pure color is diluted by white light.
3. **Brightness**: It depends upon colour intensity, which is a key factor in describing the colour sensation. The intensity is easily measurable, and the results are also easily interpretable.



Distinguish Groups of Data

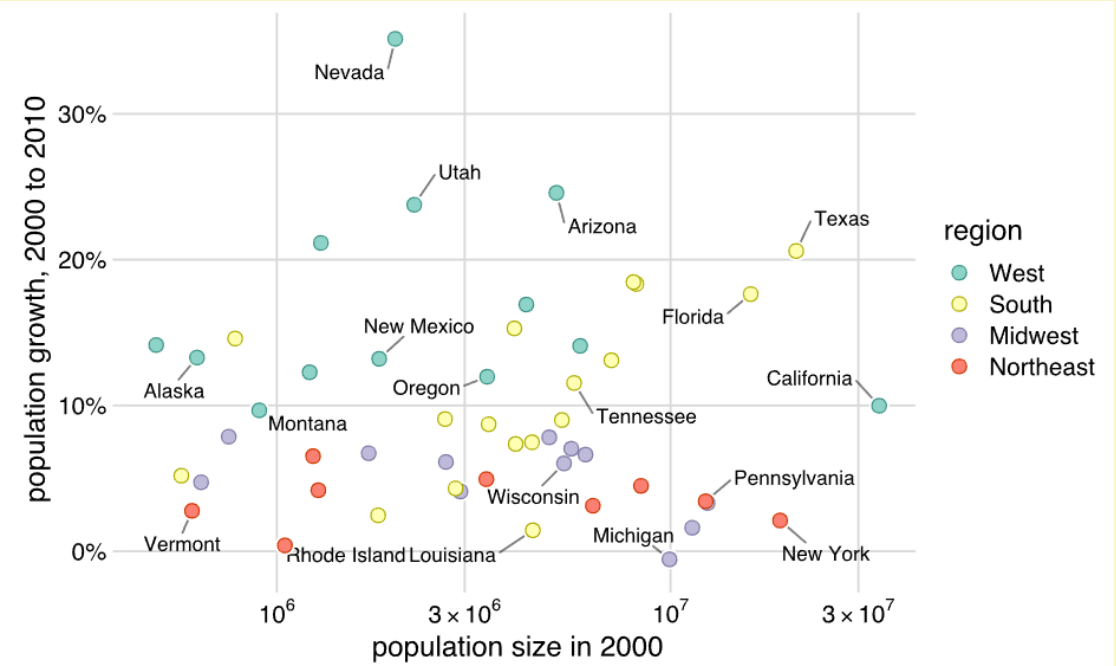
Qualitative colour scale

- Use colour to distinguish discrete items or groups that do not have an intrinsic order
- Examples: different countries on a map or different manufacturers of a certain product
- we use a **qualitative colour scale**
- Qualitative colour scale contains a finite set of specific colours that are chosen to look clearly distinct from each other while also being equivalent to each other

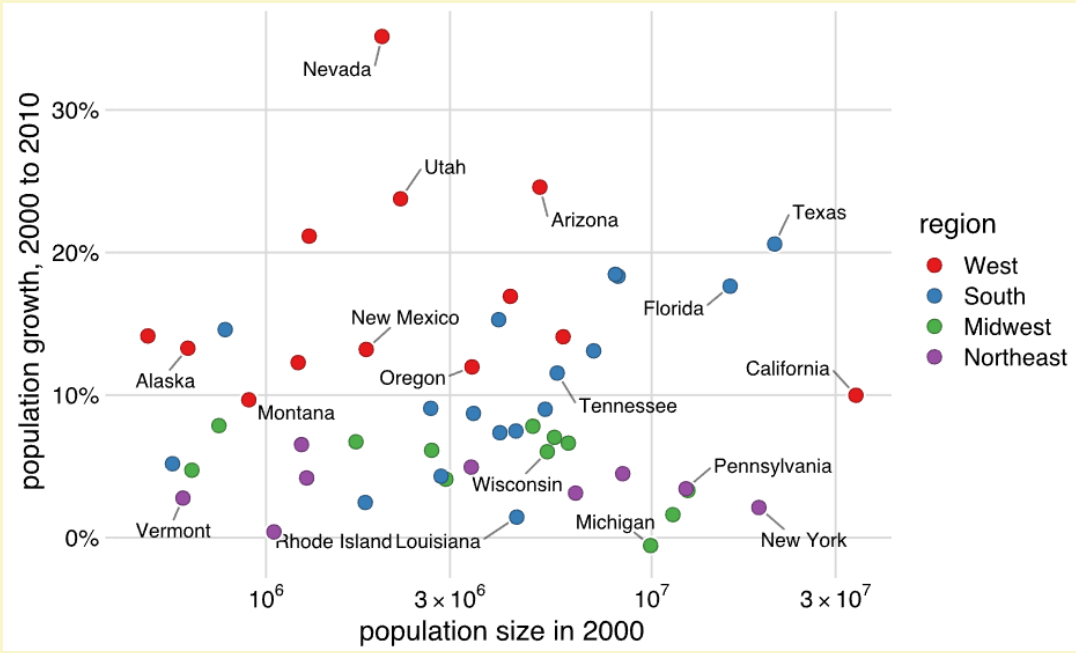


Distinguish Groups of Data

Qualitative scale examples



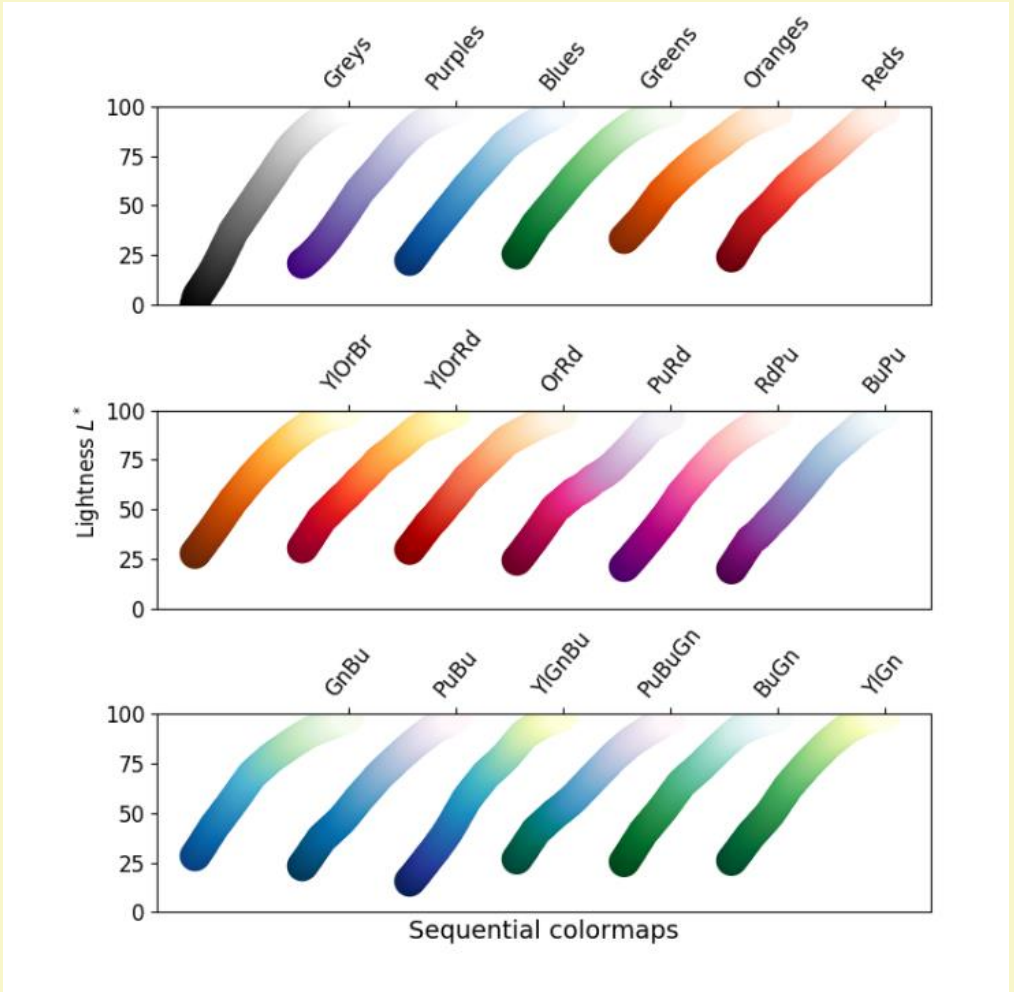
Palette name: ColorBrewer Set3



Palette name: ColorBrewer Set1

Represent Numeric Data (Sequential)

- Sequential change in lightness, and possibly saturation, of colour incrementally.
- hue can vary or stay constant.
- should be used for representing information that has a scale, or at least an ordering

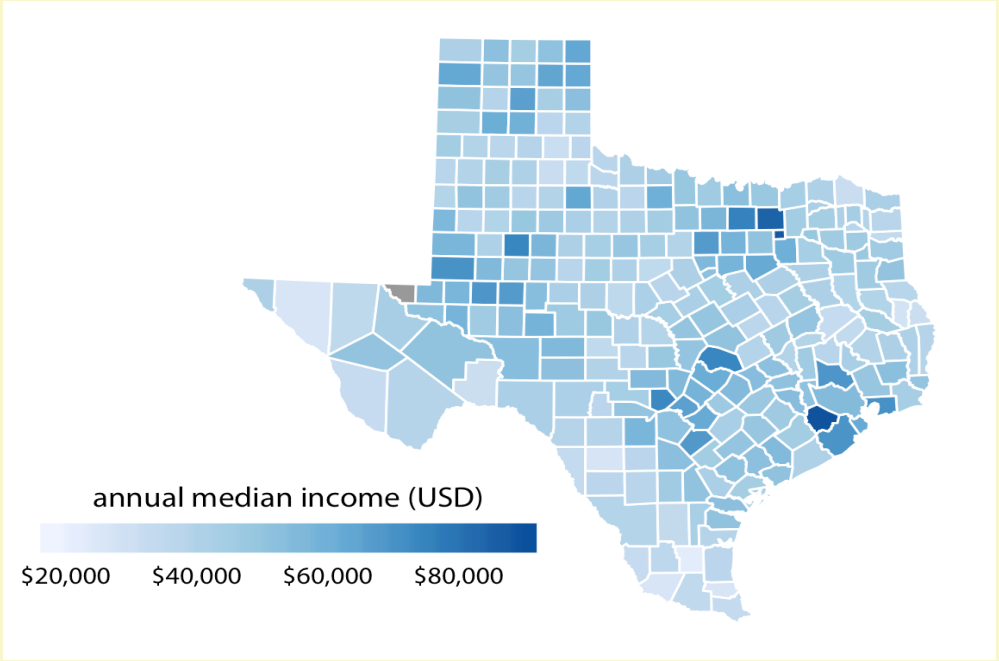


Represent Numeric Data (Sequential)

- Colour can also be used to represent data values, such as income, temperature, or speed.
- **Sequential color scale** contains a sequence of colors that clearly indicate:
- which values are larger or smaller than which other ones; and
  - how distant two specific values are from each other.

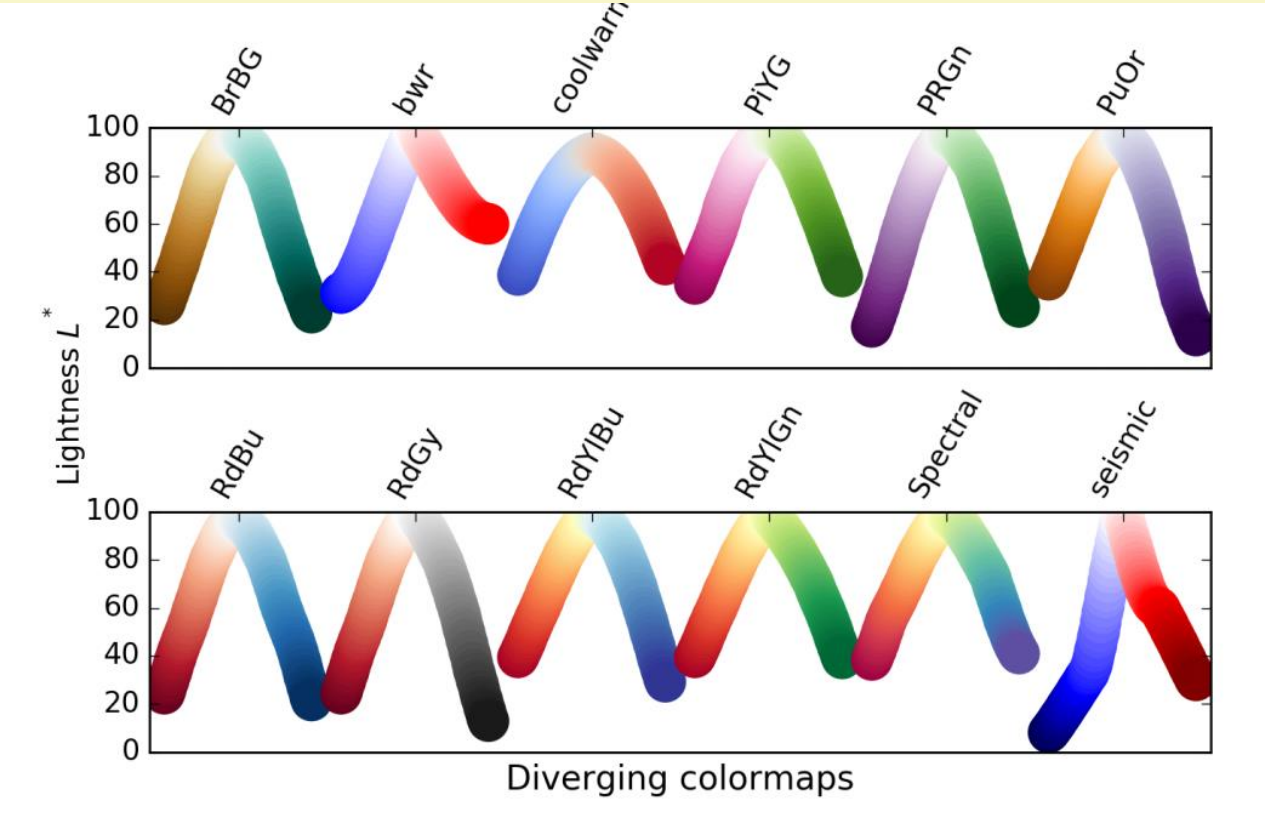
Represent Numeric Data (Sequential)

- Representing data values as colors is particularly useful when we want to show how the data values vary across geographic regions.
- We can draw a map of the geographic regions and color them by the data values. Such maps are called **choropleths**.



Represent Numeric Data (Diverging)

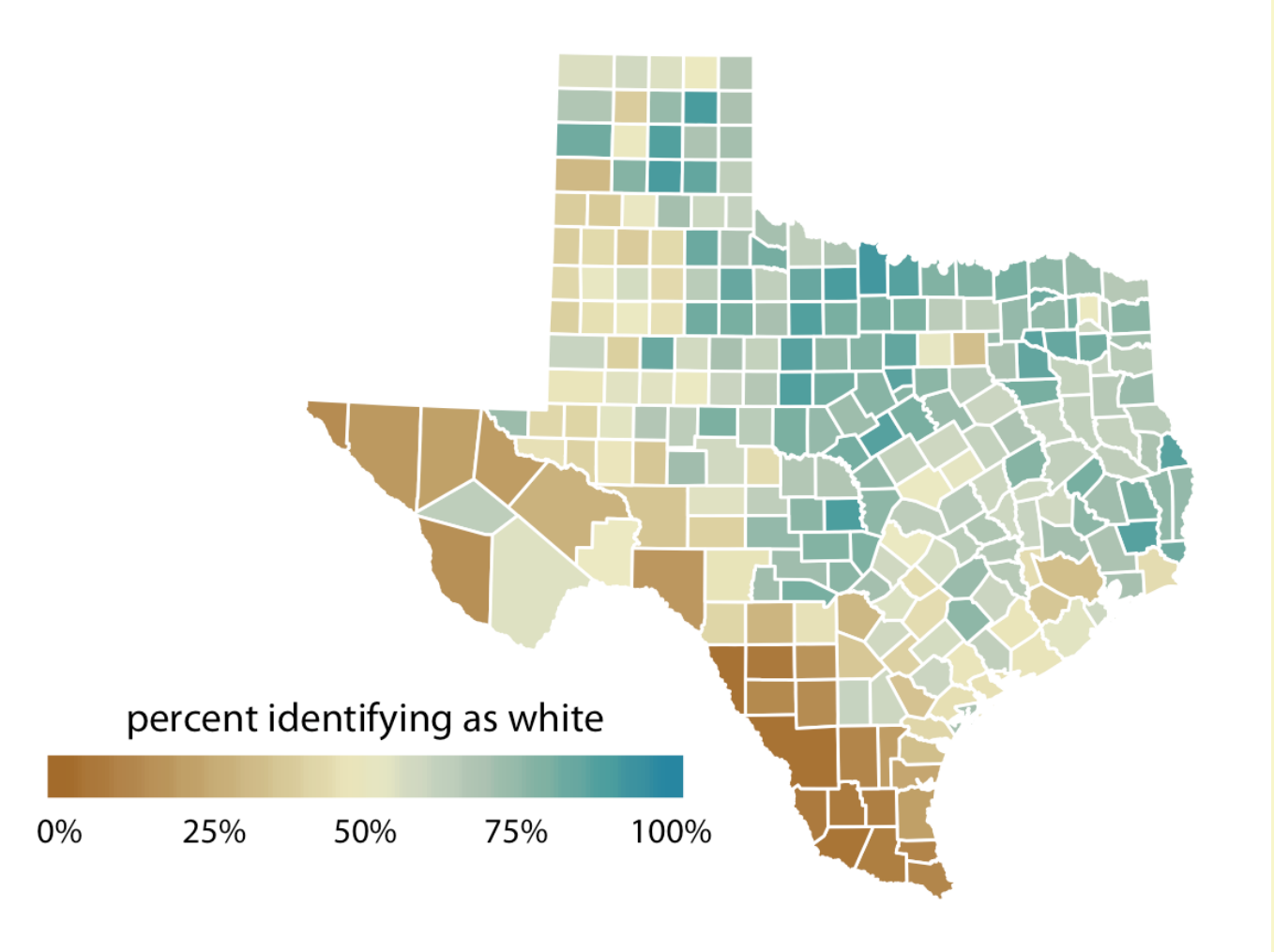
- Diverging
  - change in lightness, and possibly saturation, of two different colours that meet in the middle at an unsaturated colour
- should be used when the information being plotted has a critical middle value



Represent Numeric Data (Diverging)

- Visualise the deviation of data values in one of two directions relative to a neutral midpoint.
  - example is a dataset containing both positive and negative numbers
  - We can think of a diverging scale as two sequential scales stitched together at a common midpoint, which usually is represented by a light color

Represent Numeric Data (Diverging)

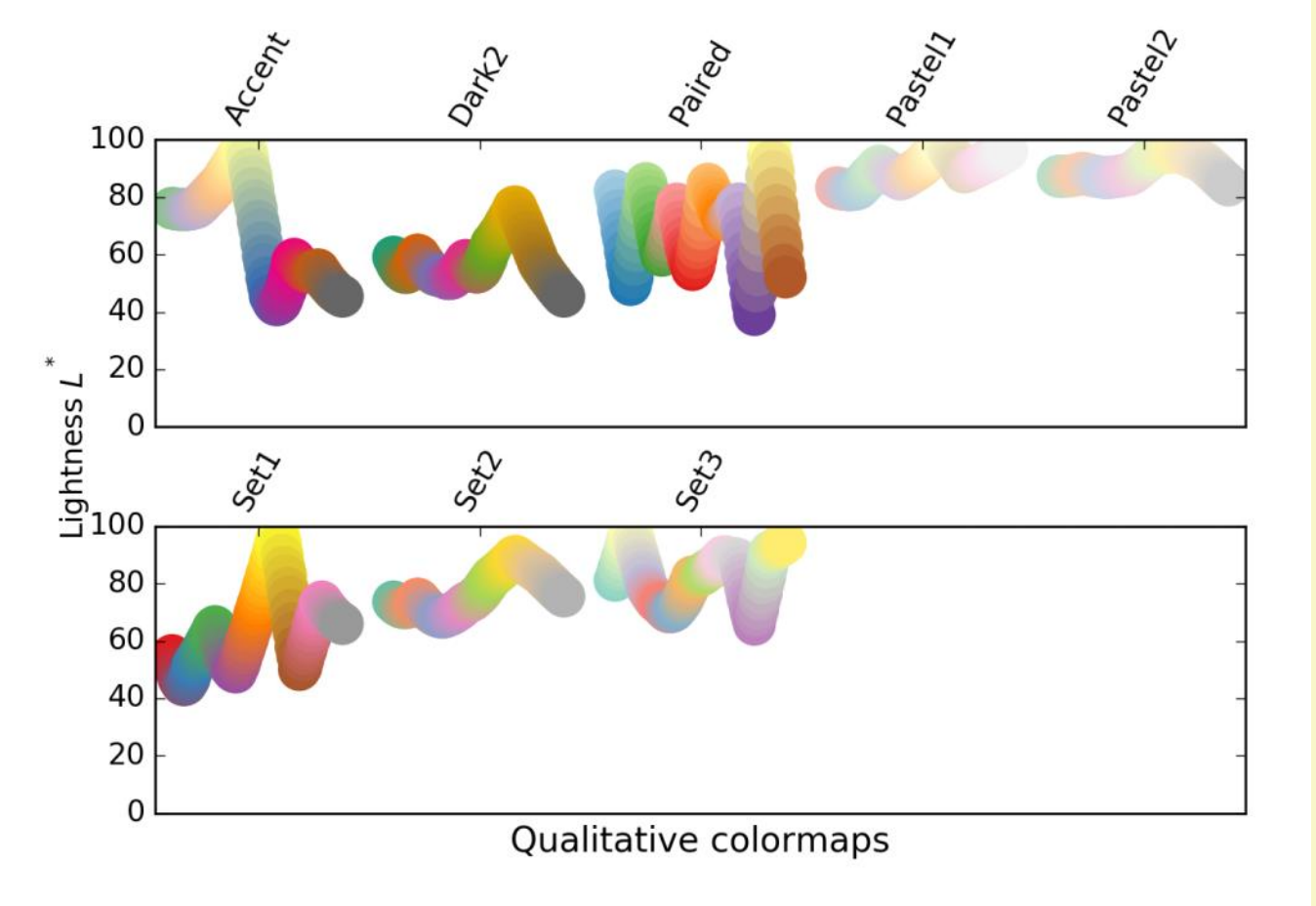


Example

Percentage of people identifying as white in Texas counties.

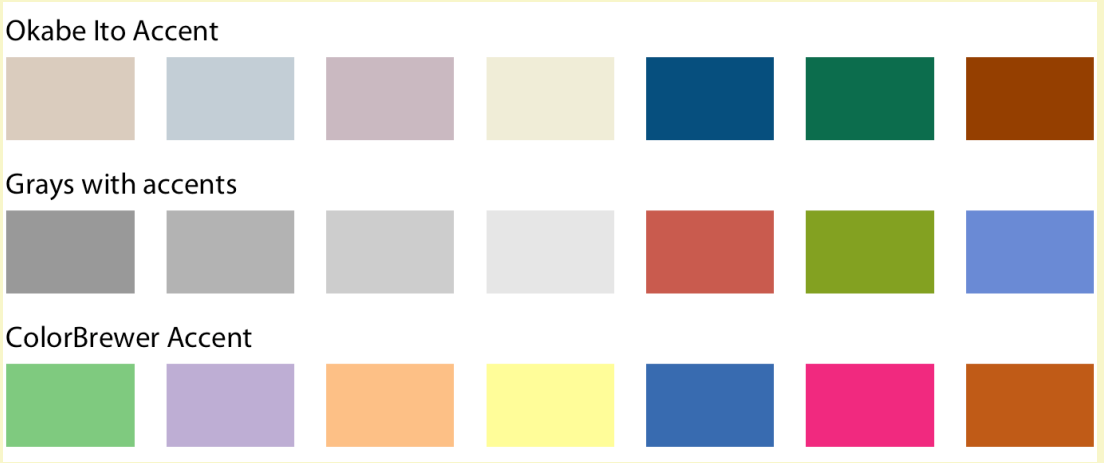
Represent Qualitative Data

- For qualitative data we often us miscellaneous colours
  - should be used to represent information which does not have an ordering and to maximise category discrimination

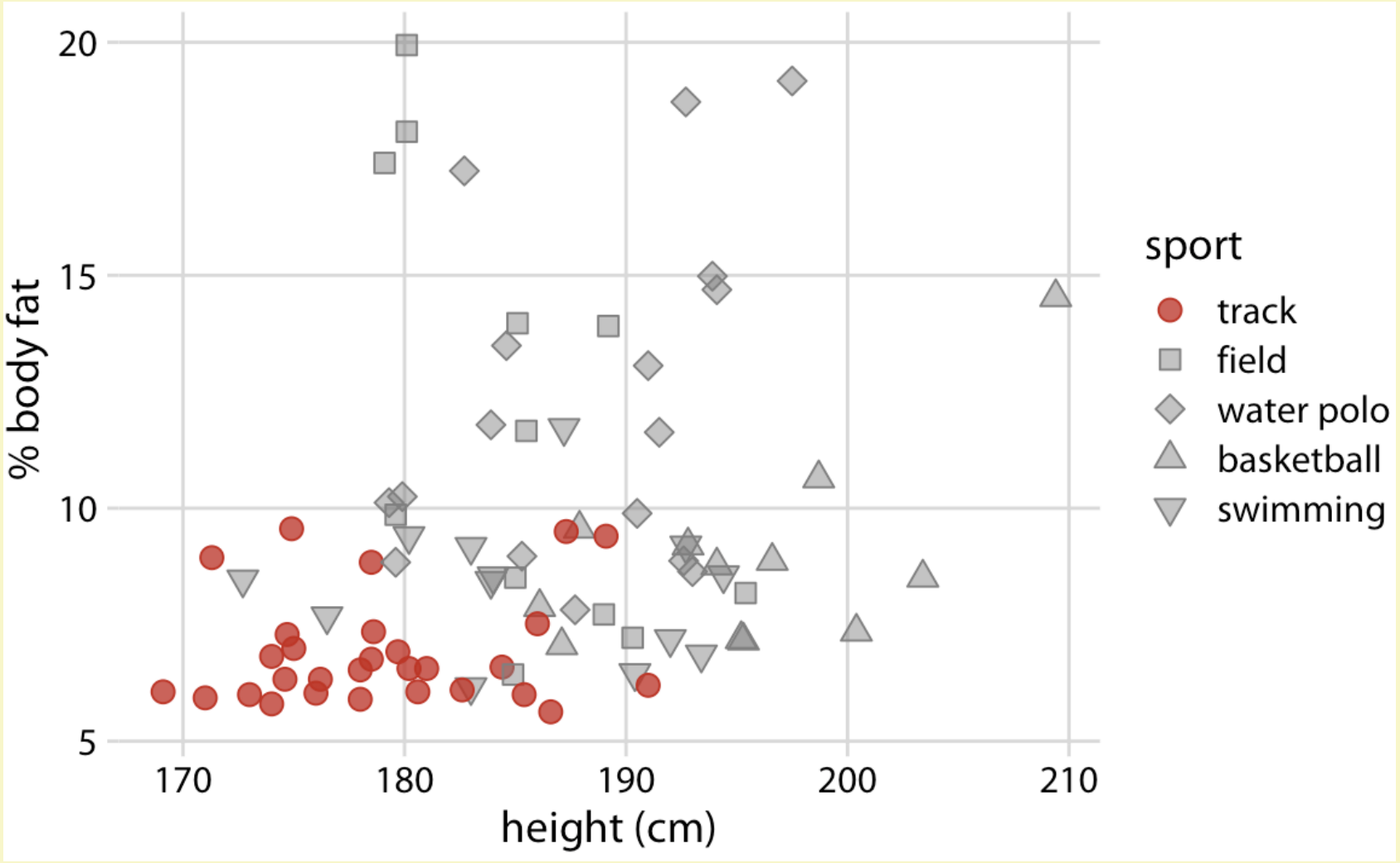


Use Colour to highlight

- Color can also be an effective tool to highlight specific elements in the data.
- highlight the figure elements by a color or set of colors that vividly stand out against the rest of the figure.
- This effect can be achieved with accent color scales, which are color scales that contain both a set of subdued colors and a matching set of stronger, darker, and/or more saturated colors



Use Colour to highlight



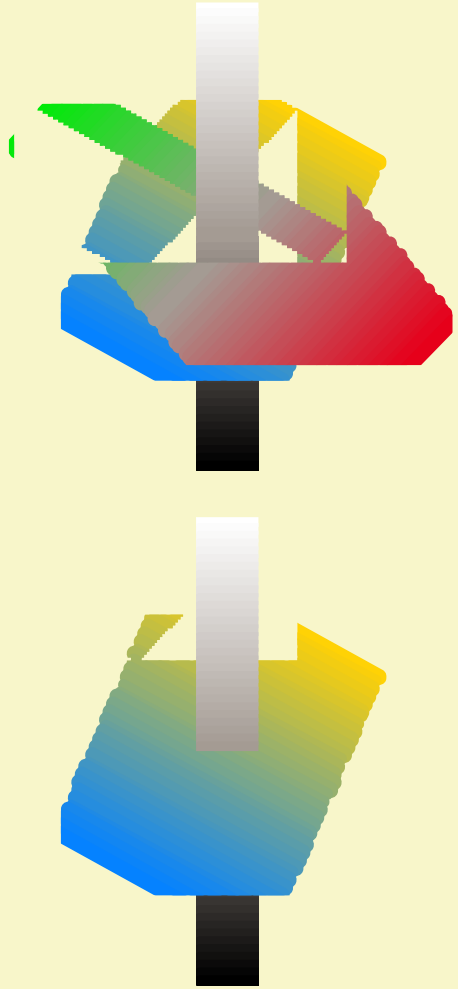
Example
Track athletes are among the shortest and leanest of male professional athletes participating in popular sports.
Data source: Telford and Cunningham (1991)

Colour Blindness

- About 10% of the male population and about 1% of the female population have some form of colour vision deficiency.
- Most common deficiencies are explained by lack of either the long-wavelength-sensitive cones or the medium-wavelength-sensitive cones.
- both result in an inability to distinguish red and green
  - R-G color blindness
- Can generate color blind acceptable palette
- Yellow blue variation is OK

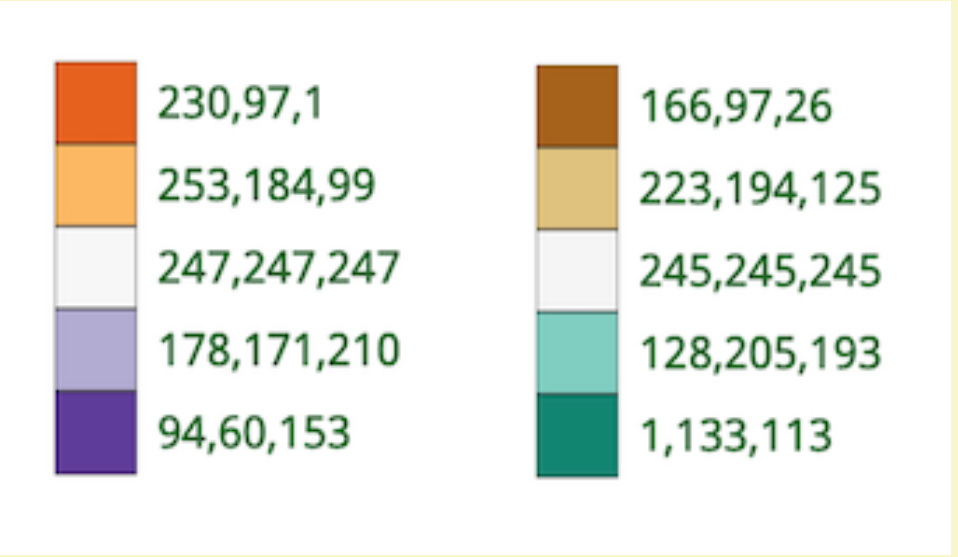
Colour Blindness

- Can generate color blind acceptable palette
- Yellow blue variation is OK

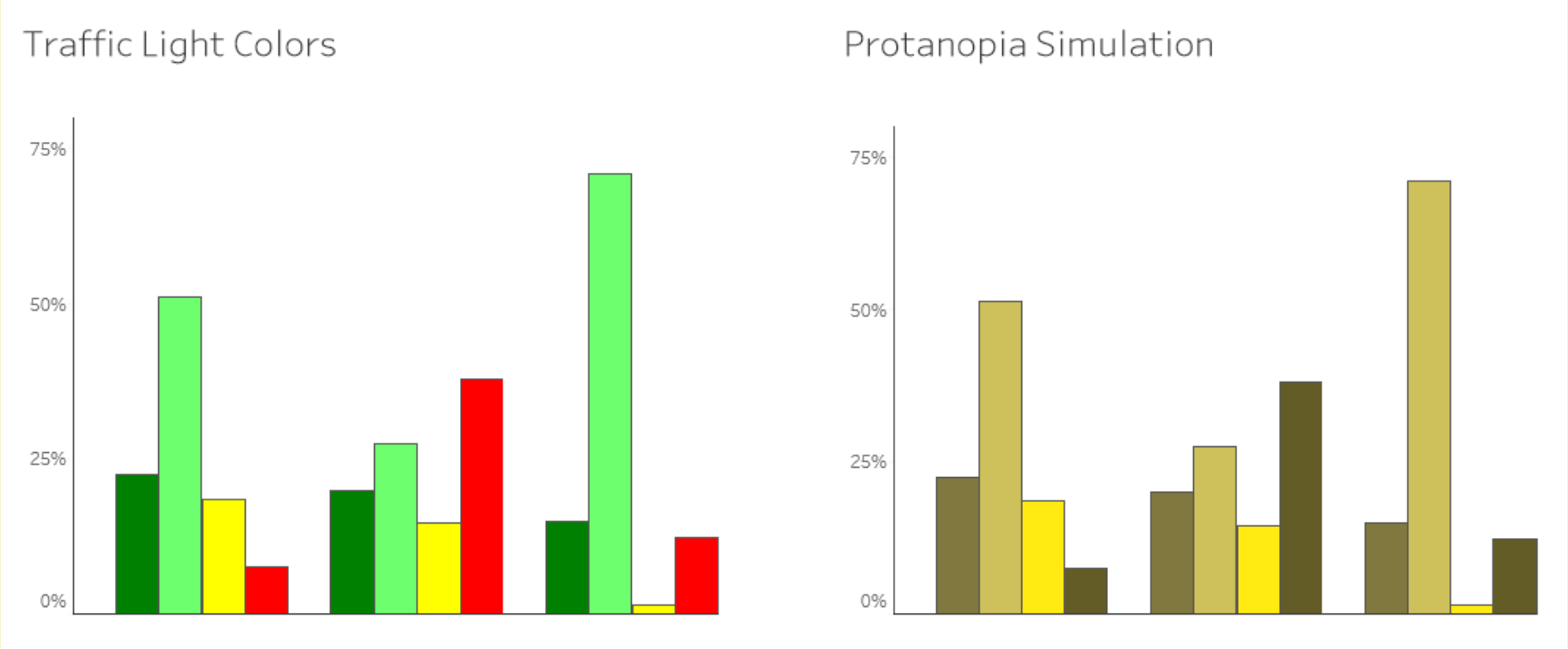


Colour Blindness

- Unfortunately, not all colour schemes will work well for every colour-blindness condition.
- That most colour schemes are *monochromatic* palettes, composed of different shades of a single colour.
  - Below, two examples created by **ColorBrewer** tool

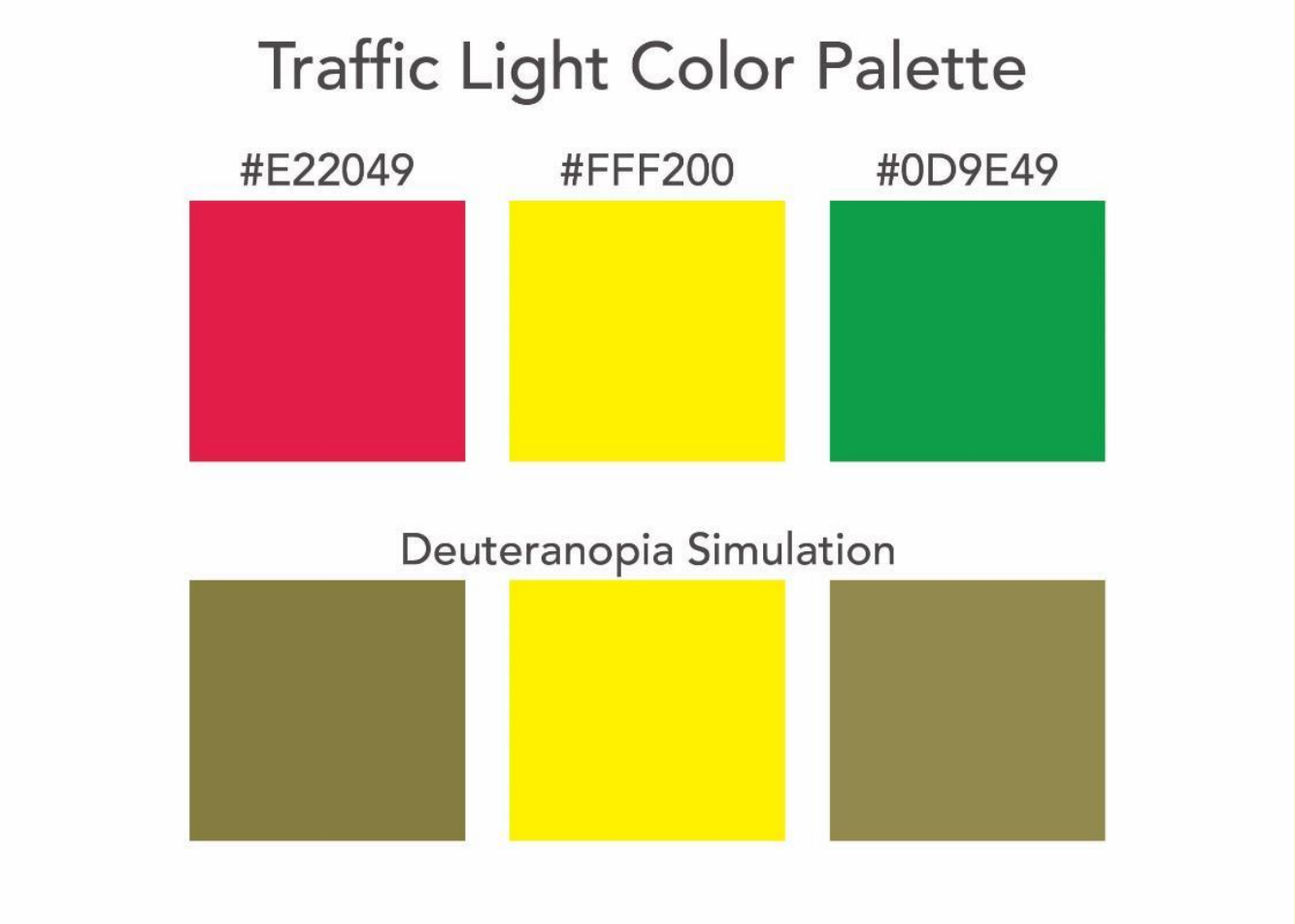


Colour Blindness



Source: *The Big Book of Dashboards*

Colour Blindness



Source: *The Big Book of Dashboards*

Concluding Remarks

- Color perception is relative
- We are sensitive to small differences
  - So we need sixteen million colors
- Not sensitive to absolute values
  - So we can only use < 10 colors for coding
- Often, a perceptually uniform colour map works well
- Note: changes in luminance are perceived much better than changes in hue
- Use the colour colorbrewer tool, link on Moodle page

Concluding Remarks

- Choosing Colormaps in Matplotlib
- use the three main types of colourmaps
  - sequential, diverging, qualitative
- Know your data!
- What is the metric?
- Is there a critical value?

Concluding Remarks

- Use luminance for detail, shape and form
- Use colour for coding – a few colours
- Strong colours for small areas – a contrast in luminance with the background
- Subtle colours can be used to segment large areas
- Minimise cognitive work!
  - Make sure that the message will be understood
  - Make sure that the visual representations will not be interpreted differently by different viewers