Coordinate Systems and Color

Bùi Tiến Lên

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KHOA CÔNG NGHỆ THÔNG TIN
TRƯỜNG ĐẠI HỌC KHOA HỌC TỰ NHIÊN

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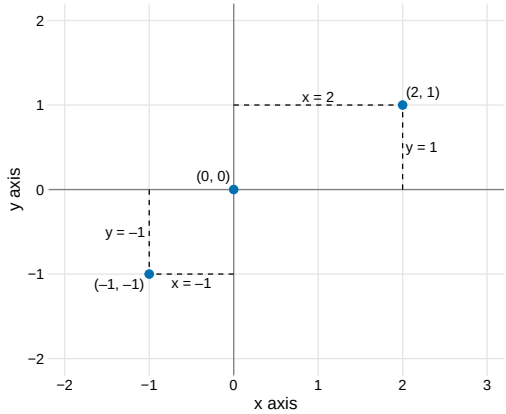
Cartesian Coordinates

- The most widely used coordinate system for data visualization is the 2D Cartesian coordinate system, where each location is uniquely specified by an x and a y value.



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Units

- Data values often come with units.
- In a Cartesian coordinate system, the spacing between grid lines along an axis corresponds to discrete steps in these data units.
- A Cartesian coordinate system can have two axes representing two different units.

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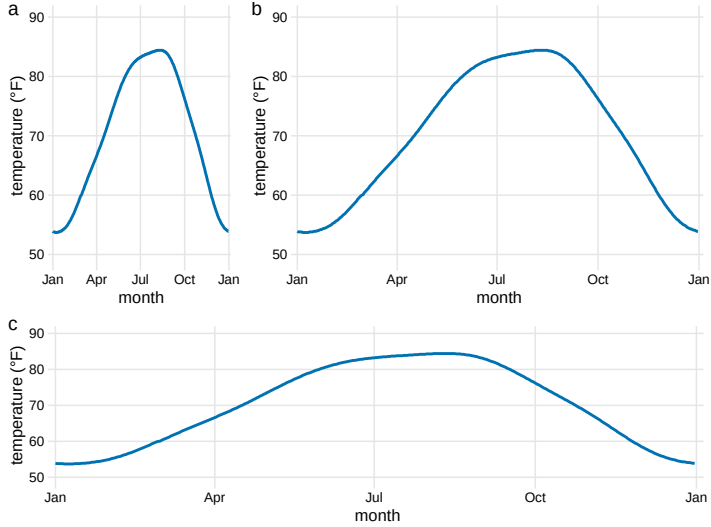
Units (cont.)



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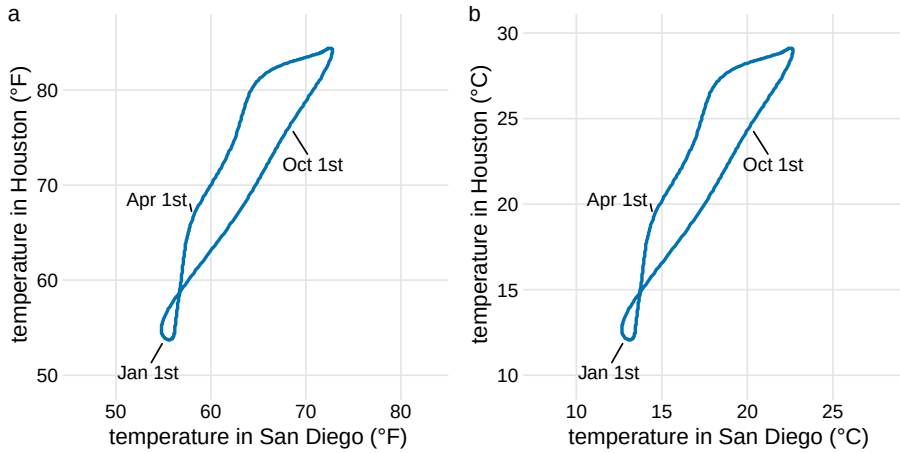

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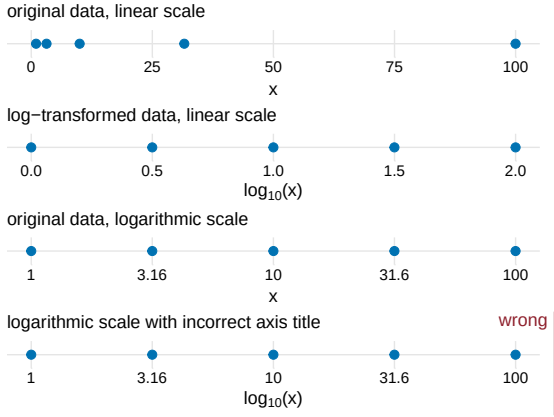
Nonlinear Axes

- The most commonly used nonlinear scale is the **logarithmic scale**



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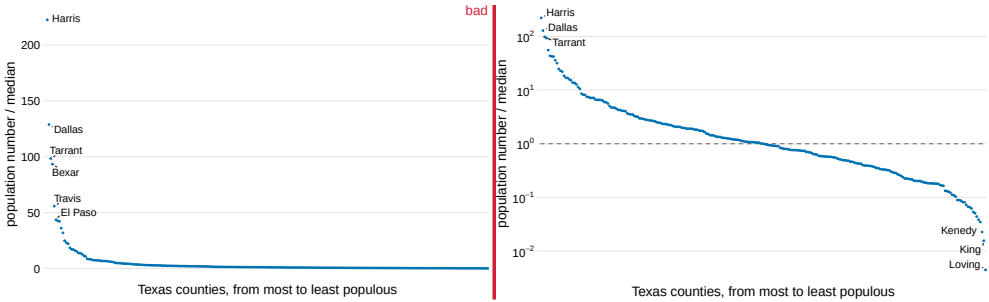
Example



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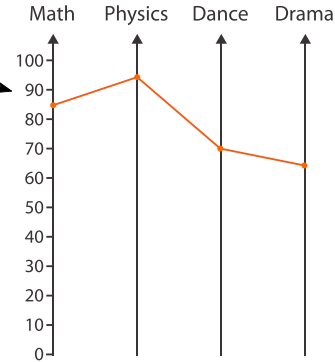
Parallel Coordinates

- **Parallel coordinates** is an approach for visualizing many quantitative attributes at once using spatial position.
- Parallel coordinates use their parallel arrangement of axes

Table

Math	Physics	Dance	Drama
85	95	70	65
90	80	60	50
65	50	90	90
50	40	95	80
40	60	80	90

Parallel Coordinates



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Circular Coordinates

- Circular Coordinates star-shaped arrangement of axes

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The Big Picture

Encode › Map

- **Color**
  - Color Encoding
    - Hue
    - Saturation
    - Luminance
  - Color Map
    - Categorical
    - Ordered
      - *Sequential*
      - *Diverging*
    - Bivariate
- **Size, Angle, Curvature, ...**
  - Length
  - Angle
  - Area
  - Curvature
  - Volume
- **Shape**
- **Motion**
  - Motion
    Direction, Rate, Frequency, ...

Color System

- Color Vision
- Color Systems

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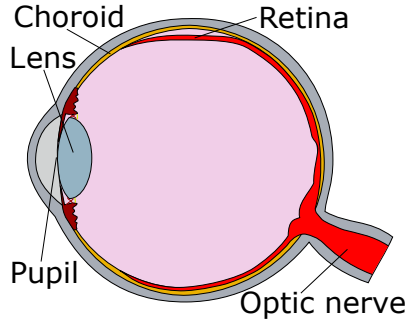
Color Vision

- The **retina** of the eye has two different kinds of receptors: rods, cones
- 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**
- The visual system processes signals into three **opponent color channels**



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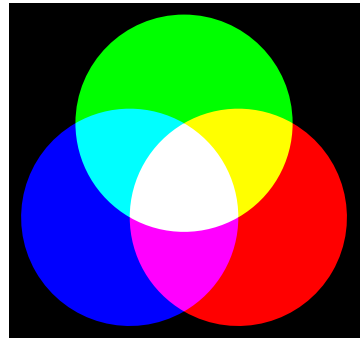
RGB System

- The **color space** of what colors the human visual system can detect is three dimensional; that is, it can be adequately described using three separate axes
- The most common color space in computer graphics is the system where colors are specified as triples of **R**ed, **G**reen, and **B**lue values, which is called the **RGB** system



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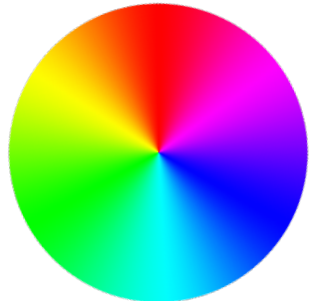
HSL System

Another color space, the **H**ue–**S**aturation–**L**ightness or **HSL** system, is more intuitive and is heavily used by artists and designers

- The **hue** axis captures what we normally think of as pure colors that are not mixed with white or black: red, blue, green, yellow, purple, and so on
- The **saturation** axis is the amount of white mixed with that pure color
- The **lightness** axis is the amount of black mixed with a color



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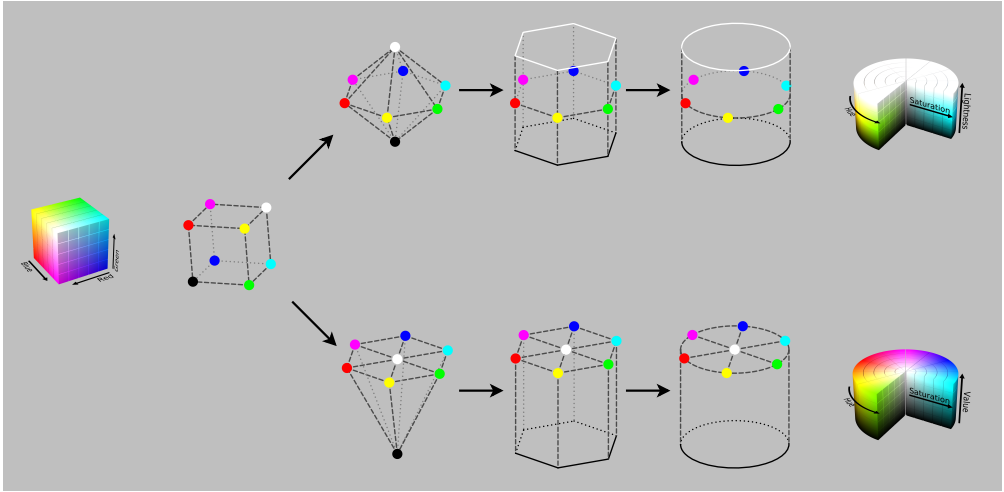
Relationship Between Color Systems



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Transparency

- A fourth channel strongly related to the other three color channels is transparency: information can be encoded by decreasing the opacity of a mark from fully opaque to completely see-through
- Transparency cannot be used independently of the other color channels
- Transparency is used most often with superimposed layers, to create a foreground layer that is distinguishable from the background layer

Choosing Set Of Colors

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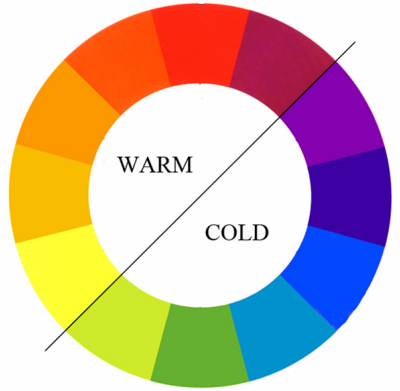
Warm vs Cool

The color wheel can be split down the middle

- reds, oranges, and yellows are warmer colors
- blues, purples, and greens are cooler colors.



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Color Meaning

Stands for: Purity, cleanliness, virtue, honesty, security, happiness
But also for: Naivety, boredom, lack of creativity
Popular in: Health care, science, technology

Stands for: Energy, excitement, warmth, adventure, enthusiasm, fun, joy
But also for: Caution, warning, rudeness
Popular in: Technology, automotive industry, entertainment, food

Stands for: Nobility, wealth, magic, spirituality, creativity, dignity, secret
But also for: Aloofness
Popular in: Beauty, wellness, yoga, spirituality, astrology

Stands for: Elegance, power, stability, strength, formality, professionalism, trustworthiness
But also for: Superficiality, arrogance, pretentiousness
Popular in: Luxury goods, fashion, finance, marketing

Stands for: Action, adventure, lust, love, urgency, energy, movement
But also for: Anger, war, violence, danger, aggression
Popular in: Food, fashion, sports, entertainment, emergency services

Stands for: Trustworthiness, confidence, security, intelligence, cleanliness, peace, strength
But also for: Coldness, distance
Popular in: Banks, insurances, politics, health care, technology, science, law

Stands for: Optimism, sun, warmth, youthfulness, fun, happiness, liveliness, good luck
But also for: Superficiality, arrogance, pretentiousness
Popular in: Food, tourism

Stands for: Finesse, honesty, romance, love, femininity, harmony, idealism
But also for: Dominance, naivety, snobbishness
Popular in: Fashion, beauty, wellness, feminine products

Stands for: Nature, environment, growth, relaxation, harmony, health, sustainability
But also for: Envy, laziness, indecision
Popular in: Science, tourism, environment, medicine, finance

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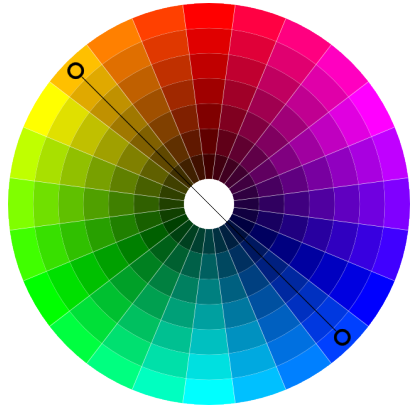
Complements

- **Pros**: This method gives high contrast between the colors in the set.
- **Cons**: It can be hard to create a balanced color-set, especially when using desaturated color as base



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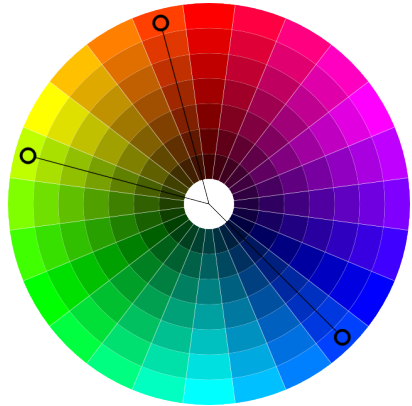
Split Complements

- **Pros**: This method gives high contrast between the colors in the set and adds more nuances over the Complements method (more colors!).
- **Cons**: It can be hard to create a balanced color-set, especially when using desaturated color as base.



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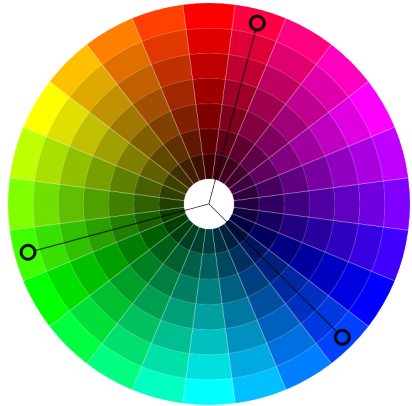
Triads

- **Pros**: The colors in the set are very harmonious, but still have a good level of contrast.
- **Cons**: Lower contrast than in Complements or SplitComplements.



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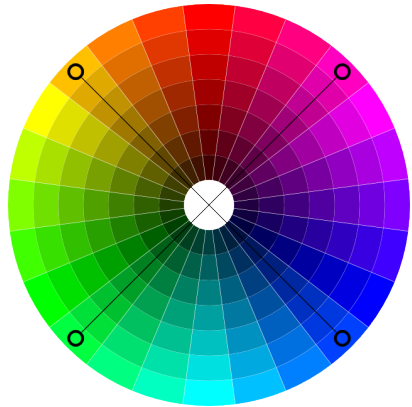
Tetrads

- **Pros**: The colors in the set are very harmonious, but have the contrast of Complements method in each pair of the colors.
- **Cons**: Because of the larger number of colors it is much harder to balance.



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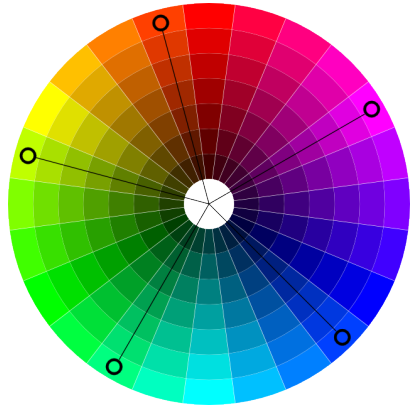
Quintads

- **Pros**: The colors in the set are very harmonious (like in Tetrads), but have lower contrast than the other sets before.
- **Cons**: Because of the larger number of colors it is much harder to balance.



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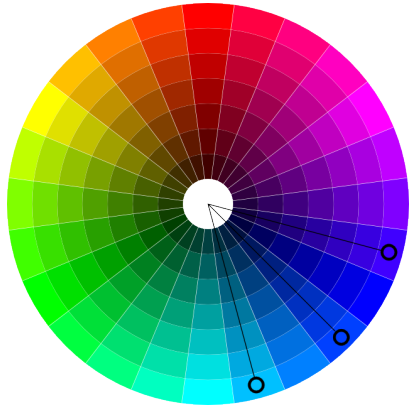
Analogous

- **Pros**: It is a rich and easy to create color set.
- **Cons**: There is not much contrast in the set.



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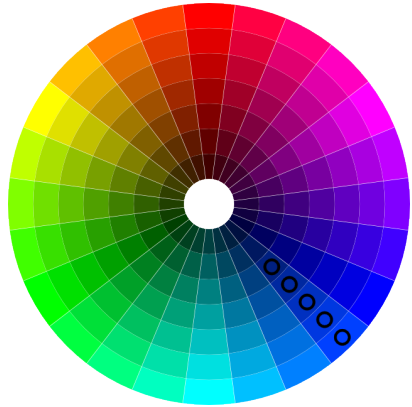
Monochromatics

- **Pros**: Very easy to create a well balanced and harmonious set.
- **Cons**: Lacks any contrast of colors.



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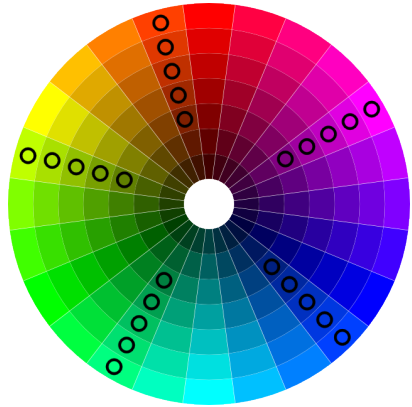
Combinations

- **Pros**: The set is very harmonious also between main colors and also in subsets. Can be used in larger sites to separate different subjects of the site by colors.
- **Cons**: Because of the larger number of colors it is much harder to balance.



Color Vision Deficiency

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Color Blindness

- Approximately 8 percent of males have **color vision deficiency** (CVD) compared to only 0.4 percent of females.
- There are three types of CVD:
  1. *Protanopia* is the lack of long-wave cones (red weak).
  2. *Deuteranopia* is the lack of medium-wave cones (green weak).
  3. *Tritanopia* is the lack of short-wave cones (blue).

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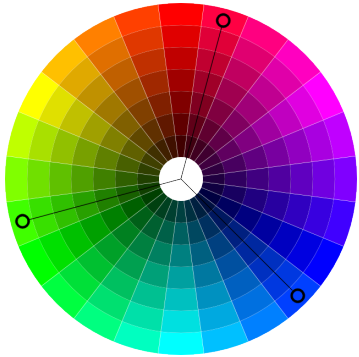
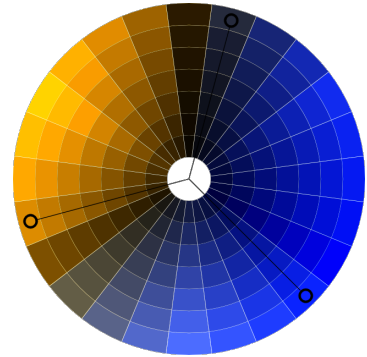
Color Blindness (cont.)

- In the left the color wheel as one with normal vision sees it, and in the right how one with Deuteranomaly





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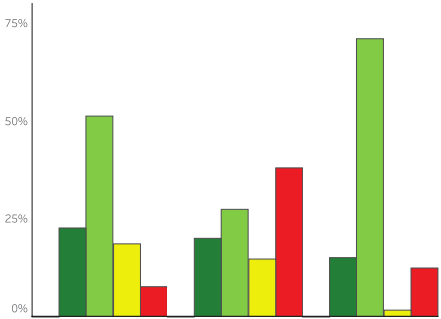
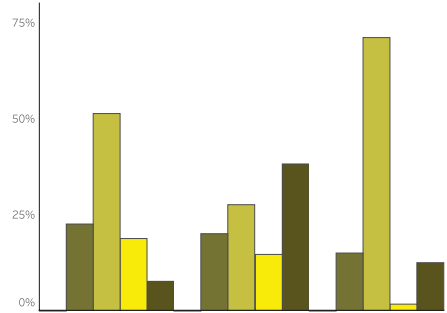
Seeing the Problem for Yourself

- Bar chart using the traffic light colors and a protanopia simulation.

Traffic Light Colors



Protanopia Simulation



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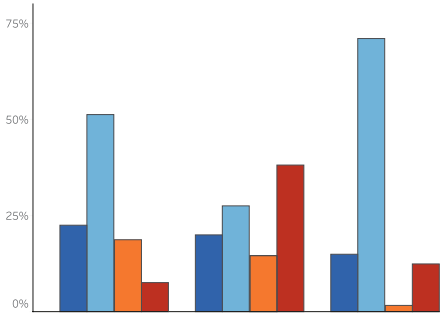
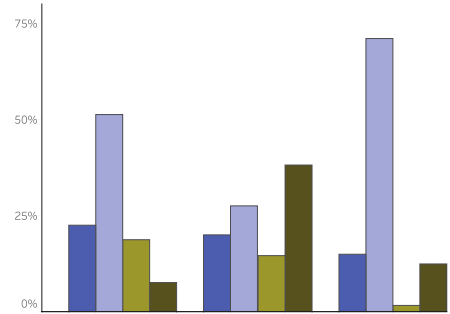
A Solution

- One common solution among data visualization practitioners is to use blue and orange. Bar chart using a color-blind-friendly blue and orange palette and a protanopia simulation.

Color-blind-Friendly Blue and Orange



Protanopia Simulation



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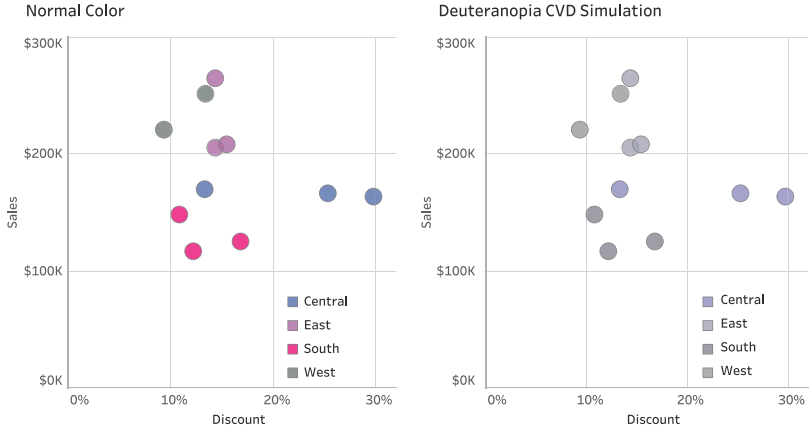
Another Problem

- Scatterplot simulating color vision deficiency for someone with deuteranopia



Colormaps

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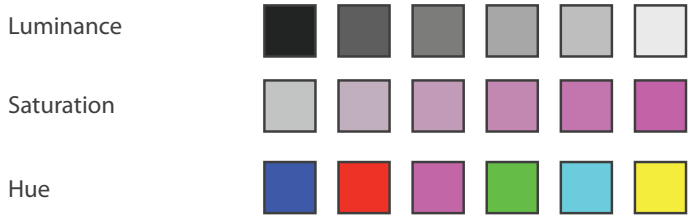
Luminance, Saturation, and Hue

- The magnitude of luminance is suitable for ordered data types
- The magnitude of saturation is also suitable for ordered data
- The identity of hue is extremely effective for categorical data and showing groupings



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Colormaps

Concept 1

A **colormap** specifies a mapping between *colors* and *data values*

- Colormaps can be **categorical** or **ordered**
  - ordered colormaps can be either **sequential** or **diverging**
- Colormaps can either be a **continuous** range of values, or **segmented** into discrete bins of color

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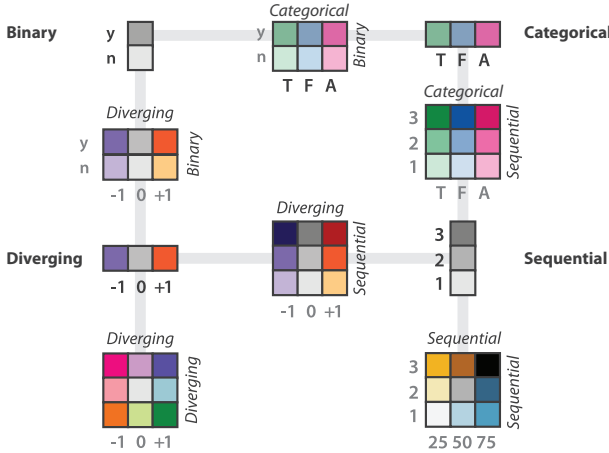
Colormaps (cont.)



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Categorical Colormaps

- A **categorical** colormap uses color to encode categories and groupings.
- Categorical colormaps are normally segmented
- Categorical colormaps are typically designed by using color as an integral identity channel to encode a single attribute
- The number of discriminable colors for coding small separated regions is limited to between six and twelve bins

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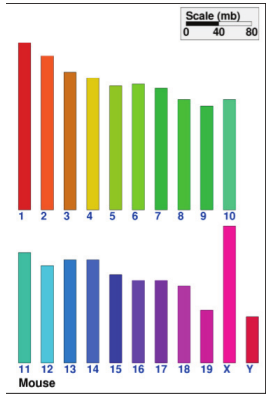
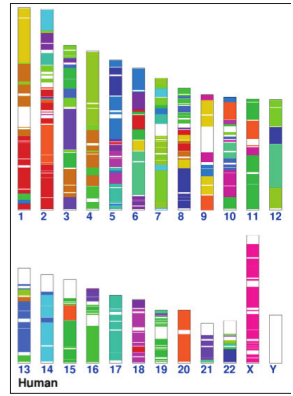
Ineffective categorical colormap use



(a)



(b)

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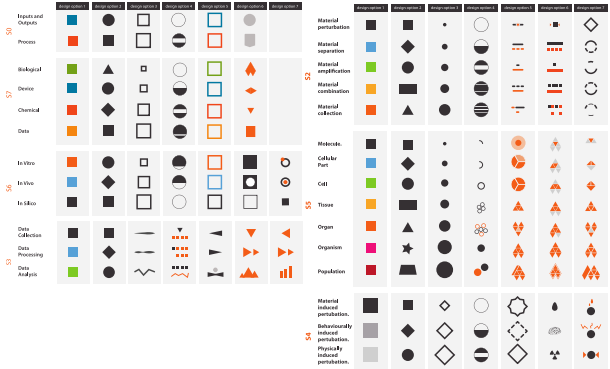
Effective categorical colormap use

- A large space of visual encoding possibilities for 27 categories was considered systematically in addition to the color channel, including size and shape channels and more complex glyphs



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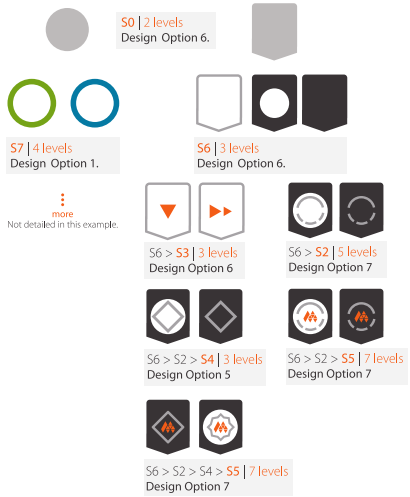
Effective categorical colormap use (cont.)

- The final design uses the color channel for only four of the categories



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Ordered Colormaps

An **ordered** colormap is appropriate for encoding ordinal or quantitative attributes

- A **sequential** colormap ranges from a minimum value to a maximum value
- A **diverging** colormap has two hues at the endpoints and a neutral color as a midpoint, such as white, gray, or black, or a high-luminance color such as yellow

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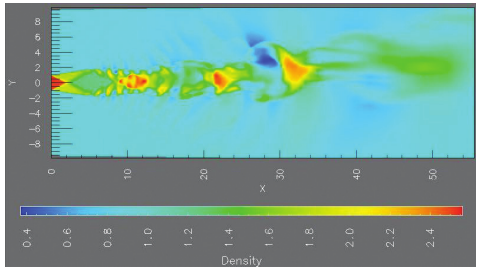
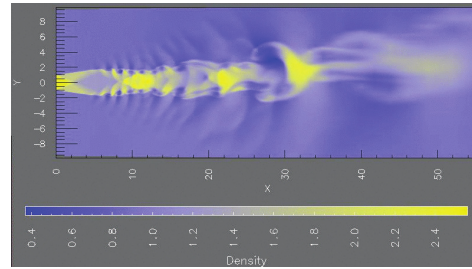
Rainbow Versus Two-hue Continuous Colormap

- Many hue (**rainbow**) vs two-hue colormaps



(a)



(b)

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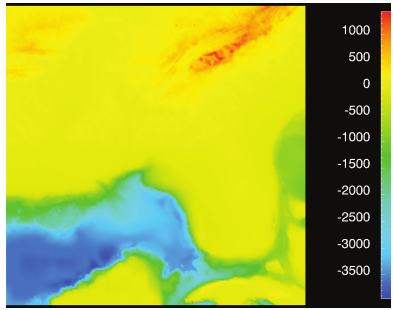
Problems With The Rainbow

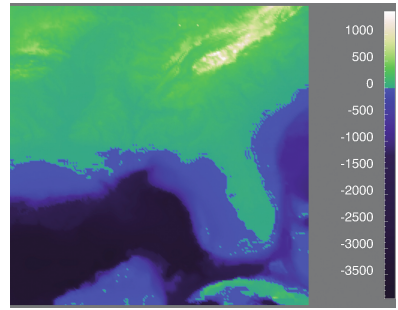
Three major problems with the common continuous rainbow colormap are

- Perceptual nonlinearity
- The expressivity mismatch of using hue for ordering
- The accuracy mismatch of using hue for fine-grained detail.

One way to address all three problems is to design **monotonically increasing luminance** colormaps



(a)



(b)

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Appropriate Use Of Rainbows

(a) The standard rainbow colormap is perceptually nonlinear.

(b) Perceptually linear rainbows are possible, but they are less bright with a decreased dynamic range.

(c) Segmented rainbows work well for categorical data when the number of categories is small.

(a)

(b)

(c)

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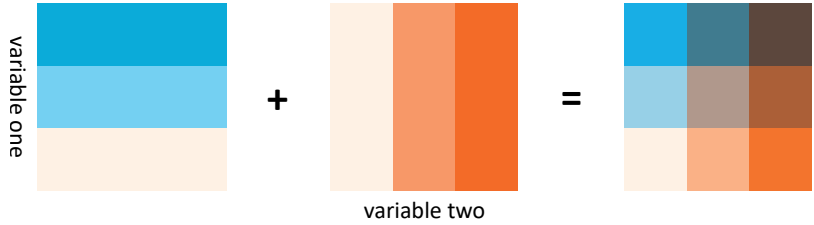
Bivariate Colormaps

- The safest use of the color channel is to visually encode a single attribute; these colormaps are known as **univariate**.
- Colormaps that encode two separate attributes are called **bivariate**.



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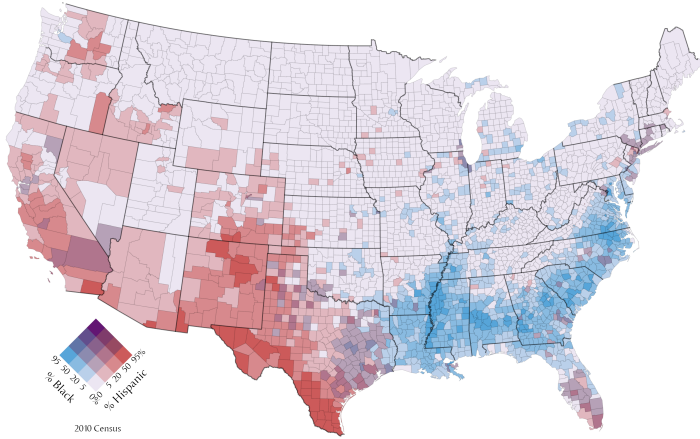
Example

Bivariate choropleth map comparing the Black (blue) and Hispanic (red) populations in the United States, 2010 census; shades of purple show significant proportions of both groups.



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