03

Human Perception and Information Processing

FACULDADE DE
CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

Notice

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Bibliography

- **Many examples are extracted and adapted from**
  - **Interactive Data Visualization: Foundations, Techniques, and Applications,**

    Matthew O. Ward, Georges Grinstein, Daniel Keim, 2015

  - **Visualization Analysis & Design,**

    Tamara Munzner, 2015

Practical information

Teams: lets check the actual situation

- **Not yet in any team !**

43368	Ricardo Manuel Rodrigues Amaral	MIEI
48157	João Carlos Raposo dos Reis	MIEI
57024	Pedro Carlos Estêvão Laranjeira	MAEBD
57918	Kamil Trojnar	MIEI

Shared folder on Google Drive

- **You have received access to a shared folder:**
  - **VID-19-20-GNN**
    - Where GNN is your group ID
    - If not please let me know
- **Proposed organization for your folder**
  - **Data and Workbooks**
  - **Papers and PDFs**
  - **Project Paper**
    - Name the files like VID-GNN-2020.MM.DD-Paper.pdf
  - **You may use overleaf to work on the paper**
  - **Goggle Docs to share drafts**

Teams: lets check the actual situation

- **Teams registration and start working on**
  - **Any question? Any issue?**
  - **Look for data**
    - No Covid-19
- **Evaluation rules - (just checking)**
  - **Next week CCMIEI will issue oficial informations**
  - **ACTUAL: Team work (50%) + 2 Tests (50%) | Exam**
  - **FCT Scnario: 2 Dates for Exams**
    - Team work (60%) + Exam(40%)
  - **Other Scenario:**
    - Team work (60%) + 30-40 min Oral(40%)

Team work require a 45 min oral - Individual grades

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Our agenda

Week		Subjects	Event
1	2-6 Mars	Overview	
2	9-13 Mars	Introduction to Data Visualization	No class
3	16-20 Mars		Team registration: Mars 20th
4	23-27 Mars		
5	30-3 April		
6	6-10 April		No class - Holliday
7	13-17 April		
8	20-24 April	Visualization Techniques	Subject Registration: 25 April
9	27-1 May		~~Test 1: April 27th~~
10	4-8 May		
11	11-15 May		Paper: May 15th
12	18-22 May	Advanced Topics	
13	25-29 May		
14	1-5 Jun	Students Support	TP Implementation: June 5th
15	8-12 Jun	Oral Sessions	~~Test 2: June 7th;~~ Oral

Our agenda

Week		Subjects	Event
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2	9-13 Mars	Introduction to Data Visualization	**No class**
3	16-20 Mars		**Team registration: Mars 20th**
4	23-27 Mars		
5	30-3 April		
6	6-10 April		**No class - Holliday**
7	13-17 April		
8	20-24 April	Visualization Techniques	**Subject Registration: 25 April**
9	27-1 May		
10	4-8 May		
11	11-15 May		**Paper: May 15th**
12	18-22 May	Advanced Topics	
13	25-29 May		
14	1-5 Jun	Students Support	**TP Implementation: June 5th**
15	8-12 Jun	Oral Sessions	**Oral Sessions**

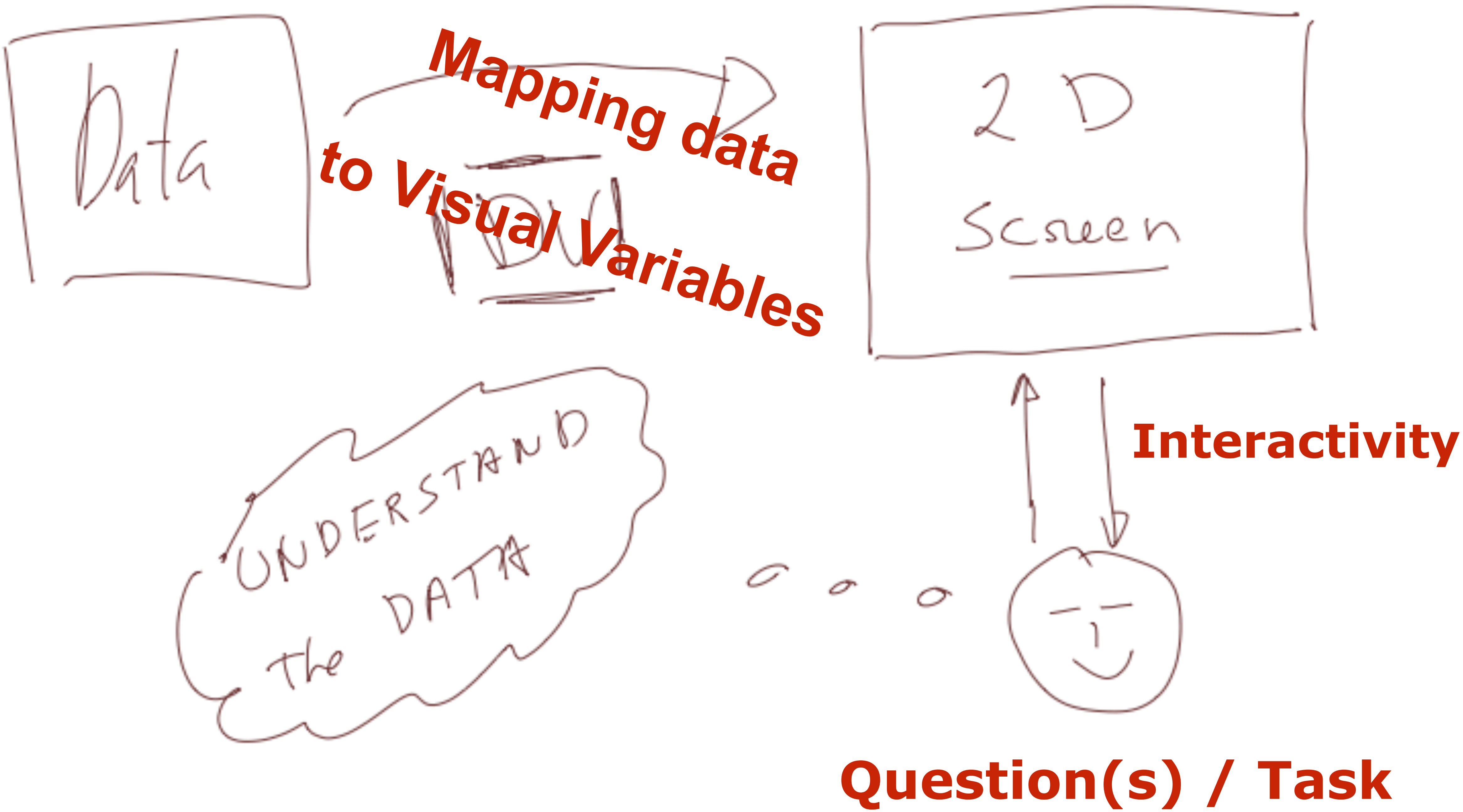
?

Recommended activities

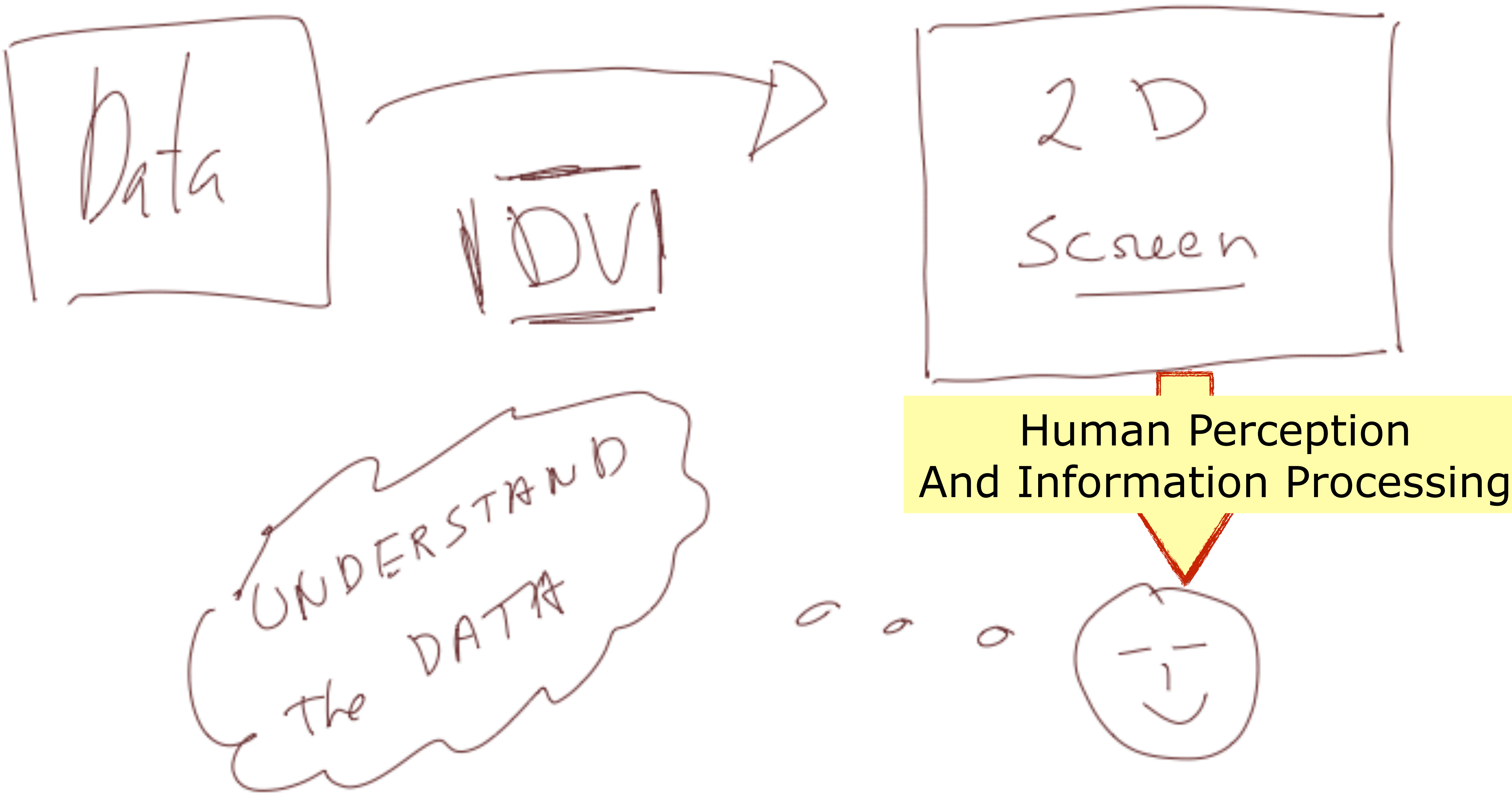
- **Start to seek for the elements to choose your subject**
  - **Data**
    - **https://www.kaggle.com/datasets**
    - Look for data-providers. For instance look at this:
      - https://sqlbelle.com/2015/01/16/data-sets-for-bianalyticsvisualization-projects/
      - https://www.springboard.com/blog/free-public-data-sets-data-science-project/
      - http://infosthetics.com
      - http://www.ipcc-data.org/observ/clim/cru_ts2_1.html
  - **Questions that worth (at least to you) to be addressed**
  - **Type of visualizations that can be useful**
  - **Papers that address the same or similar, or just related to the problems that you consider**

Never Forget !

What is the core idea of Interactive Data Visualization?



What is the core idea of Interactive Data Visualization?



Question(s) / Task

Table of Contents

- **What Is Perception?**
- **Physiology**
- **Perceptual Processing**
- **Perception in Visualization**
- **Metrics**
- **Cognition**

Introduction to Data Visualization

What Is Visualization?
Relationship between Visualization and Other Fields.
The Visualization Process.
Data Foundations.
Human Perception and Information Processing.
Semiology of Graphical Symbols.
The Visual Variables.

Visualization Techniques

Visualization Techniques for Spatial Data
Visualization Techniques for Geospatial Data
Visualization Techniques for Time-Oriented Data
Visualization Techniques for Multivariate Data
Visualization Techniques for Trees, Graphs, and Networks
Text and Document Visualization

Interaction Concepts and Techniques

Interaction Operators, Operands and Spaces (screen, object, data, attributes)
Visualization Structure Space (Components of the Data Visualization)
Animating Transformations
Interaction Control
Designing Effective Visualizations
Comparing and Evaluating Visualization Techniques

Visualization Systems

Systems Based on Data Type
Systems Based on Analysis Type
Text Analysis and Visualization
Modern Integrated Visualization Systems
Toolkits

Table of Contents

- **What Is Perception?**
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Recap !

What is perception?

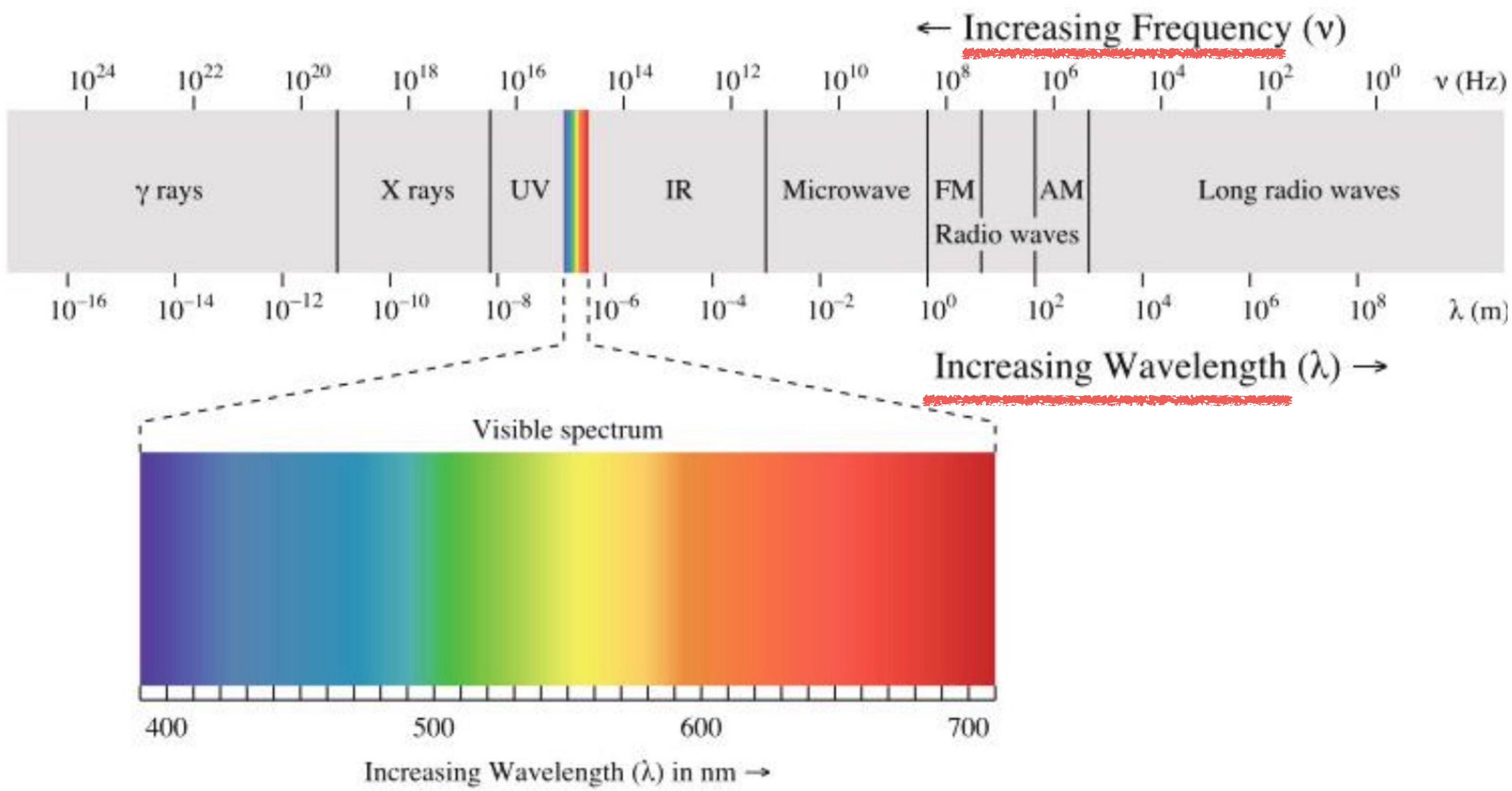
- **Most define perception as the process of:**
  - **recognizing (being aware of);**
  - **organizing (gathering and storing);**
  - **and interpreting (binding to knowledge) sensory information.**

- **Perception is the process by which we interpret the world around us, forming a mental representation of the environment.**

- **The brain makes assumptions about the world to overcome the inherent ambiguity in all sensory data, and in response to the task at hand.**

Visible Spectrum

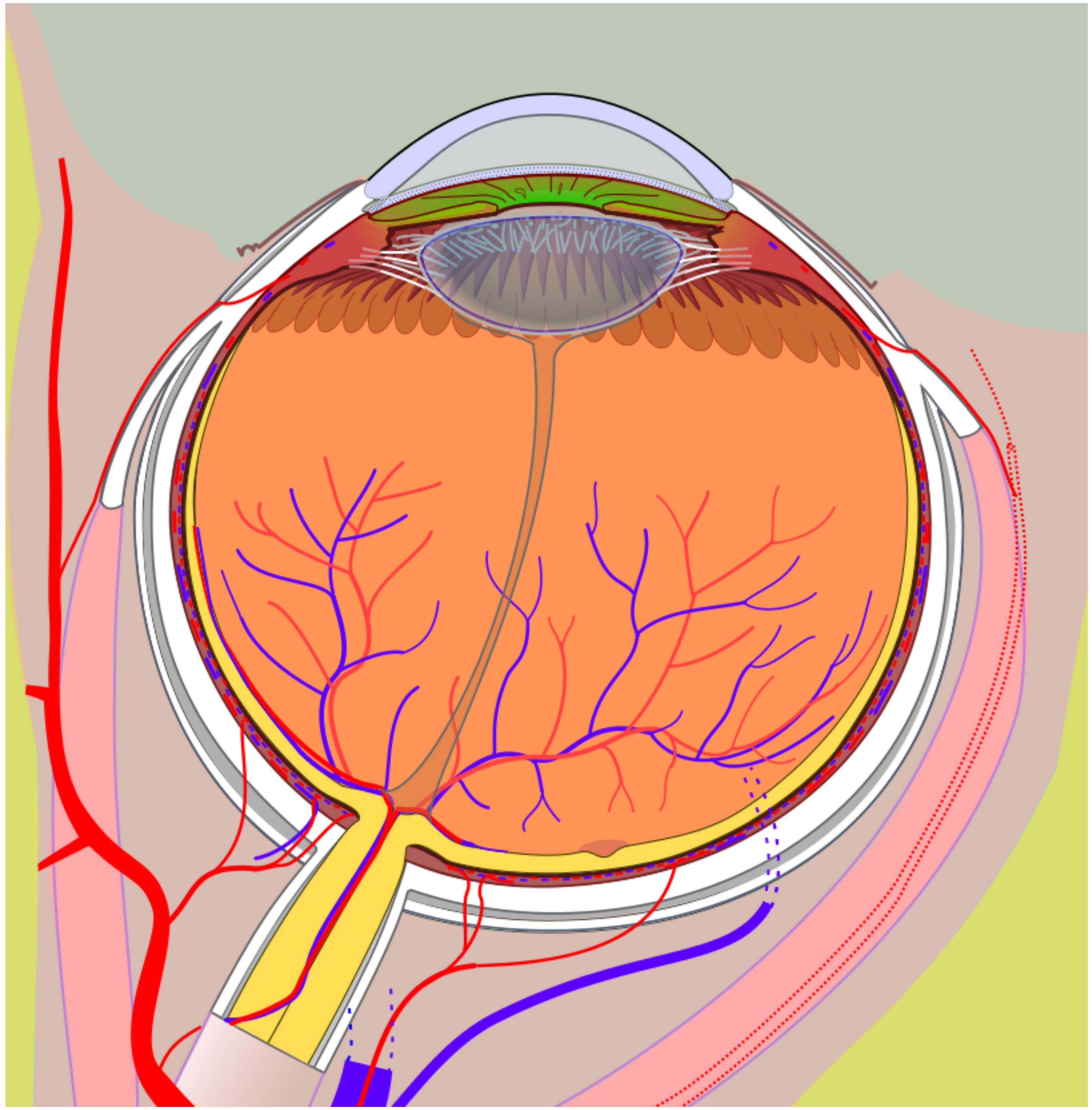
- **The range is very much dependent on the individual.**



- **Color blindness and total blindness in humans are the result of an individual not responding to certain wavelengths.**

Figure 3.8 - (Matthew Ward, et. all)

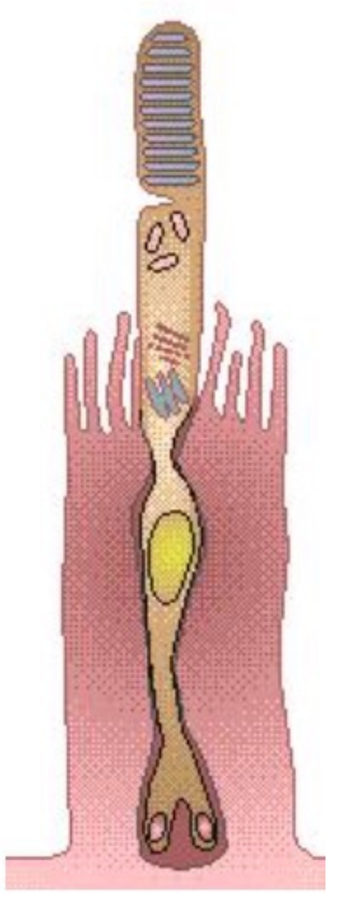
Anatomy of the Visual System: Retina



Anatomy of the Visual System: Retina

- **Two types of photosensitive cells: rods and cones**
  - **Rods are primarily responsible for intensity perception. They are associated with scotopic vision, night vision, operating in clusters for increased sensitivity in very low light conditions.**

Rods

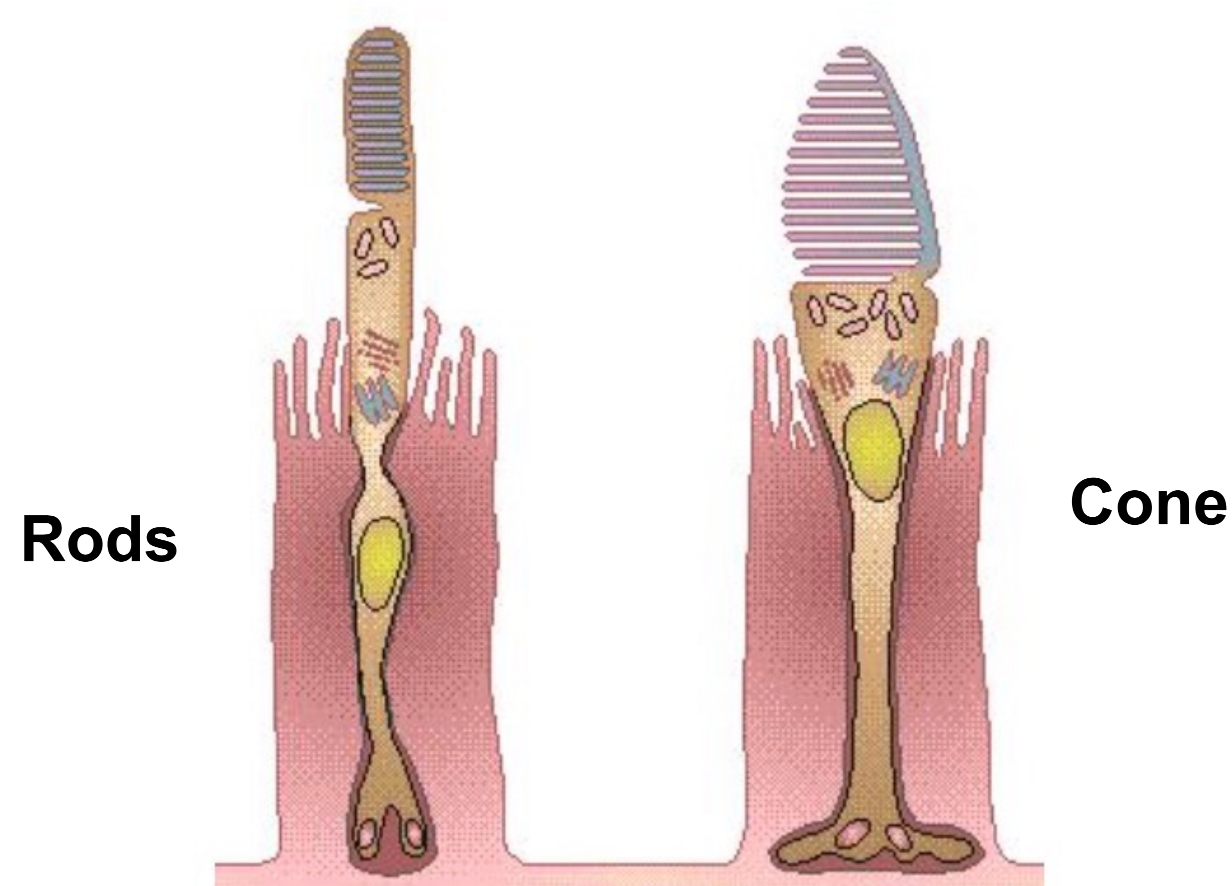


Human rod (left) and cone (right).

Anatomy of the Visual System: Retina

- **Two types of photosensitive cells: rods and cones**
  - **Rods are primarily responsible for intensity perception. They are associated with scotopic vision, night vision, operating in clusters for increased sensitivity in very low light conditions.**
  - **Cones for color perception**

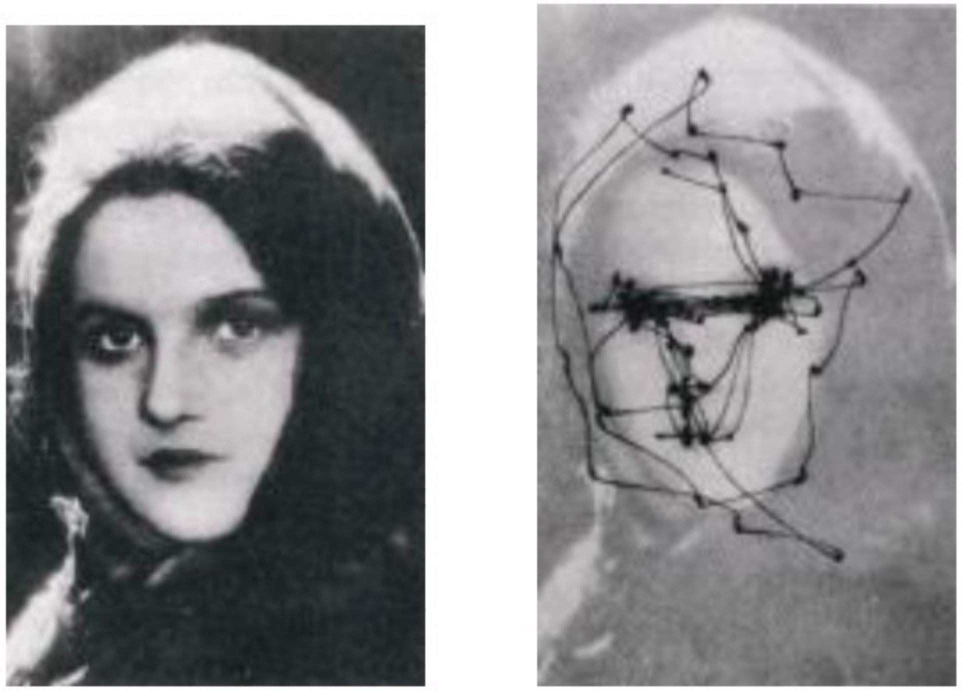
- **Rods are typically ten times more sensitive to light than cones**



Human rod (left) and cone (right). (Image © Colour4Free.)

Eye Movement

- **Saccadic eye movements: these result from multiple targets of interest (not necessarily conscious).**
- **The eye moves as much as 1000 degrees per second, bringing the gaze on those targets within 25 msec.**
  - **It holds its position once on target.**
  - **Selected targets are determined in the frontal part of the cerebral cortex.**
  - **The selection is discriminatory, dependent on a variety of parameters, and somewhat random.**



(a) (b)

(a) The face used to study eye tracking. (b) The results of the tracking gaze.

Figure 3.15 - (Matthew Ward, et. all)

Eye Movement

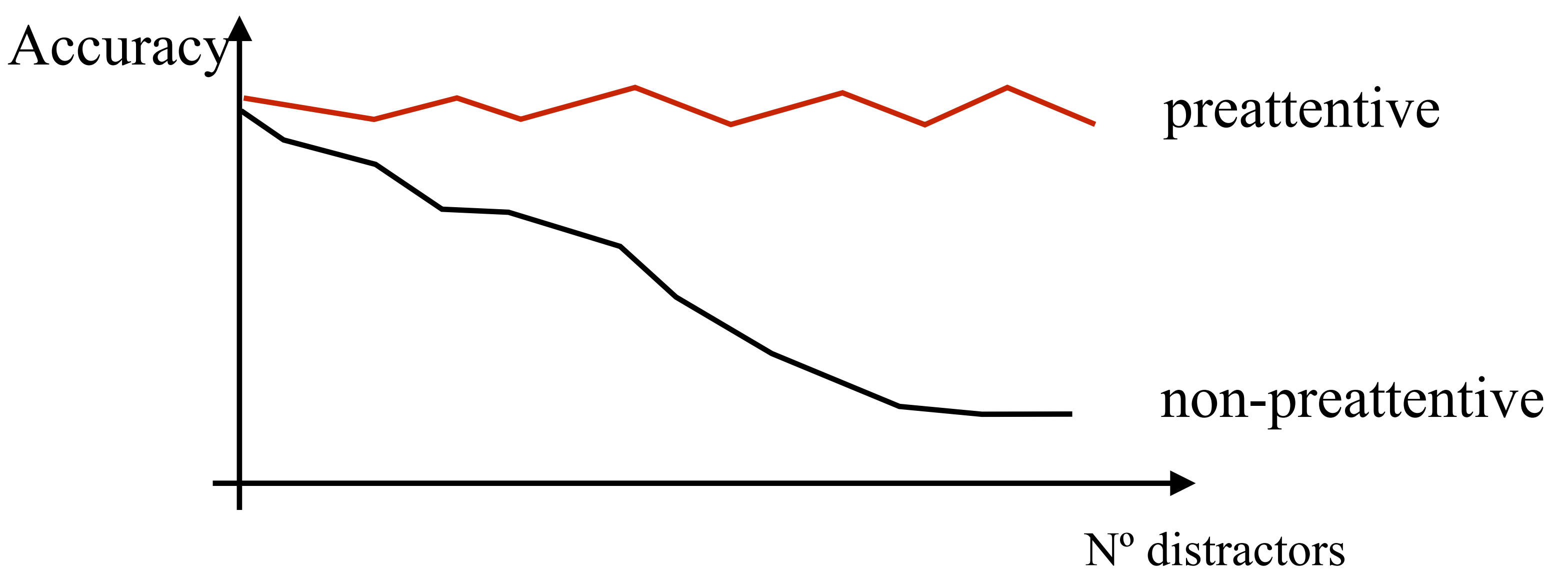
- **Saccadic masking or suppression occurs during two states between saccadic views.**
  - **The gap produced is ignored (some say blocked).**
  - **A continuous flow of information is interpreted, one that makes sense.**
  - **The higher-level visual system filters out the blurred images acquired by the low-level one, and only the two saccadic stop views are seen.**

“Preattentive” visual tasks

- **Target detection.**
  - **Users rapidly and accurately detect the presence or absence of a “target” element with a unique visual feature within a field of distractor elements.**
- **Boundary detection.**
  - **Users rapidly and accurately detect a texture boundary between two groups of elements, where all of the elements in each group have a common visual.**
- **Region tracking.**
  - **Users track one or more elements with a unique visual feature as they move in time and space.**
- **Counting and estimation**
  - **Users count or estimate the number of elements with a unique visual feature.**

Feature Integration Theory (Anne Treisman)

- **Measuring preattentive task performance:**
  - **accuracy:**
    - **the display is shown for a small, fixed exposure duration, then removed from the screen (200 to 250 msec).**
    - **The number of distractors in a scene is repeatedly increased**
    - **If viewers can complete the task accurately, regardless of the number of distractors, the feature used to define the target is assumed to be preattentive**



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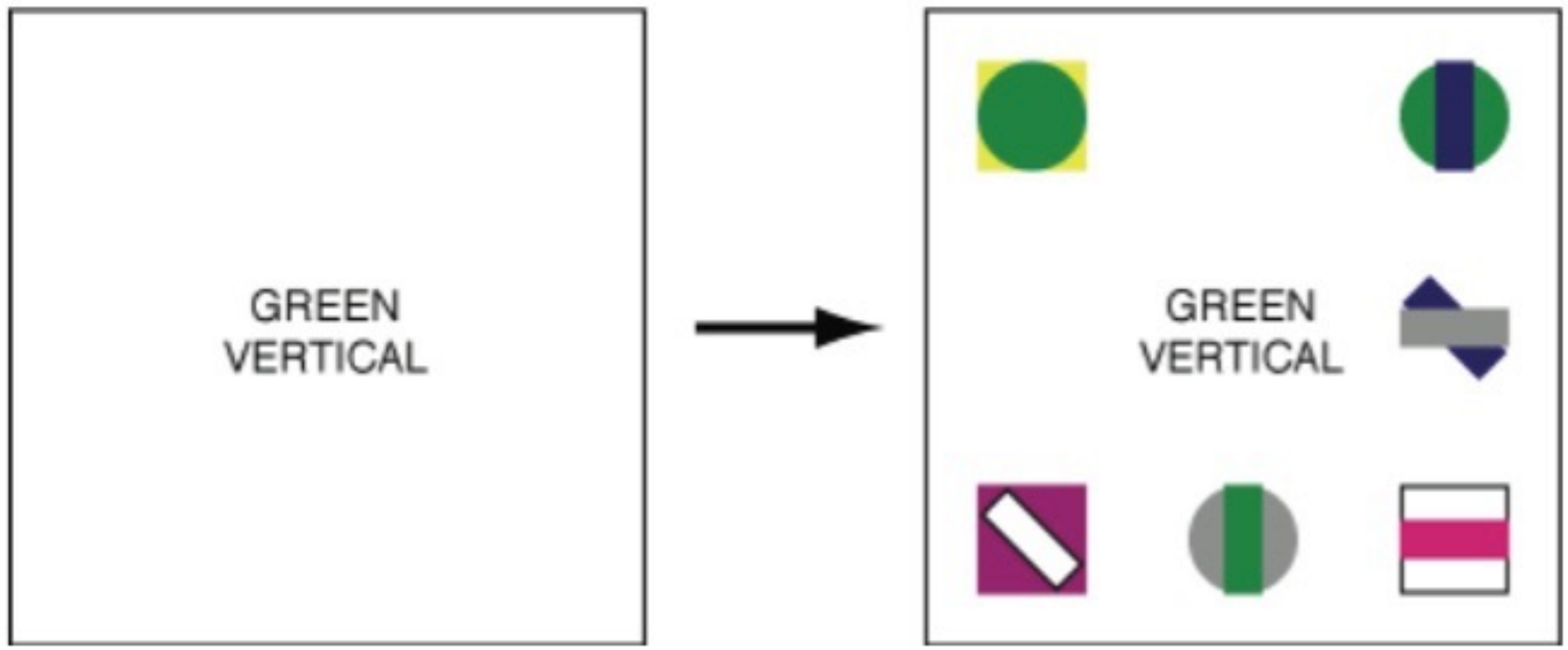
Warnings from Anne Treisman

- Some of visual features that are detected preattentively are asymmetric:
  - A sloped line in a sea of vertical lines can be detected preattentively
  - A vertical line in a sea of sloped lines cannot be detected preattentively
- Different types of background distractors may have a impact on the target feature
- Relaxing the strict dichotomy of features being detected as being either in parallel or in serial
  - For example, a long vertical line can be detected immediately among a group of short vertical lines.
  - As the length of the target shrinks, the search time increases, because the target is harder to distinguish from its distractors.

Postattentive Vision

- **Traditional search**



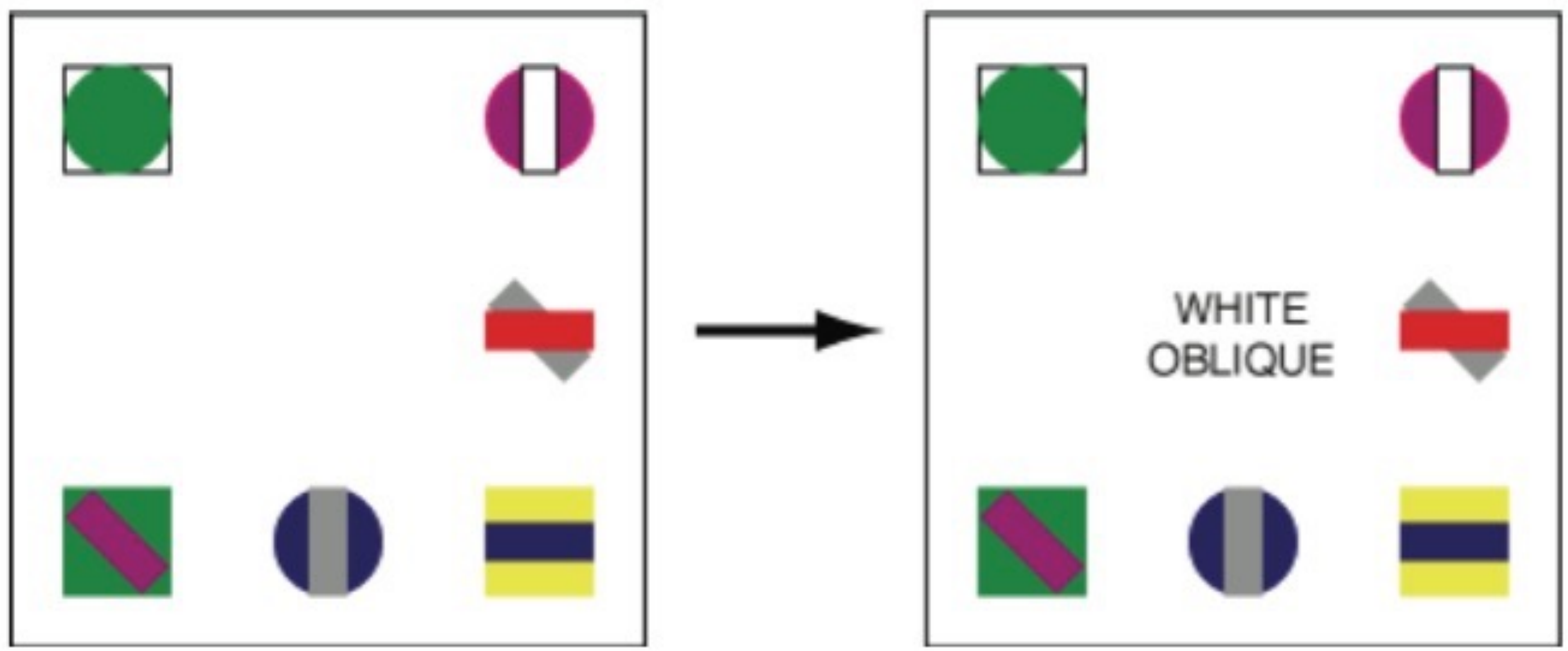
Search for color-and-shape conjunction targets:

- no preview of the scene is shown (although text identifying the target is shown prior to the search)
- in this case, the green vertical target is present

Figure 3.27 - (Matthew Ward, et. all)

Postattentive Vision

- **Postattentive search**



Search for color-and-shape conjunction targets:

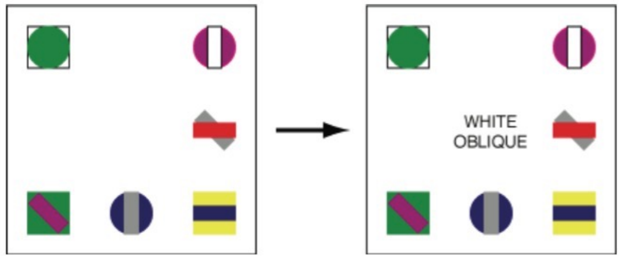
- **a preview of the scene is shown, followed by text identifying the target;**
- **in this case, a white oblique target is not present**

Figure 3.27 - (Matthew Ward, et. all)

Postattentive Vision

- **Postattentive search**
  - **The display to be searched was shown to the user for a specific duration (up to 300 msec)**
  - **Text identifying the target was then inserted into the scene**
  - **Results showed that the postattentive search was as slow (or slower) than the traditional search, with approximately 25–40 msec per object required for the target present trials.**

- **Previewing the scene provides no advantage to the viewer for finding a conjunction target**



Change Blindness

- **The goal of human vision is not to create a replica or image of the seen world in our heads.**

- **A much better metaphor for vision is that of a dynamic and ongoing construction project, where the products being built are short-lived models of the external world that are specifically designed for the current visually guided tasks of the viewer.**

- **What we "see" when confronted with a new scene depends as much on our goals and expectations as it does on the array of light that enters our eyes.**

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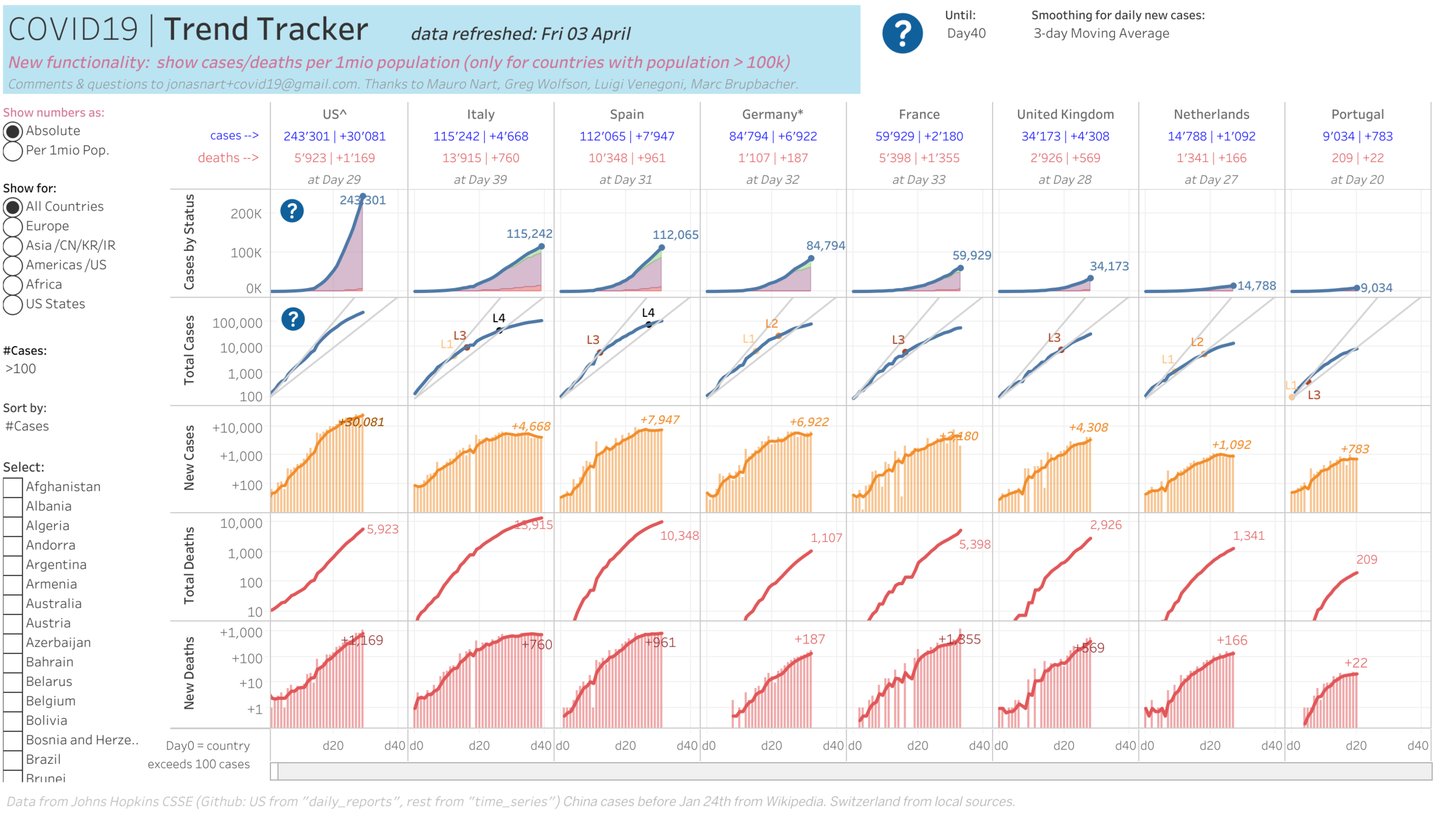
10 Minutes break

https://www.tableau.com/covid-19-coronavirus-data-resources



Perception in Visualization

Perceptual Processing

- **A painter-like visualization of weather conditions over the Rocky Mountains across Utah, Wyoming, and Colorado:**
  - **temperature is mapped to color (dark blues for cold, to bright pinks for hot);**
  - **precipitation is mapped to orientation (tilting right for heavier rainfall);**
  - **wind speed is mapped to coverage (less background showing through for stronger winds),**
  - **pressure is mapped to size (larger strokes for higher pressure).**

Figure 3.31 - (Matthew Ward, et. all)

Perceptual Processing

- **Color**
- **Texture**
- **Motion**
- **Memory issues**

Color

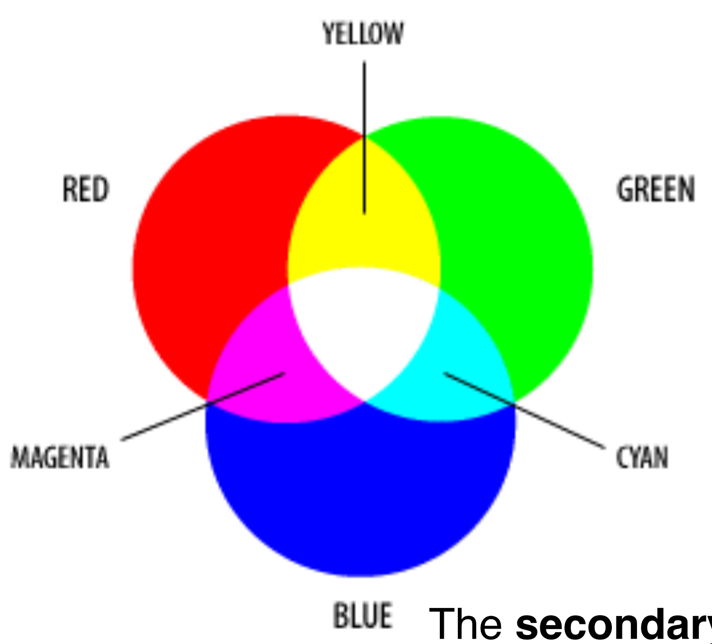
- **Recommended reading:**
  - **Subtleties of Color**
    - **http://earthobservatory.nasa.gov/blogs/elegantfigures/2013/08/05/subtleties-of-color-part-1-of-6/**
  - **Color Models**
    - **http://dba.med.sc.edu/price/irf/Adobe_tg/models/main.html**
- **Check:**
  - **http://colorbrewer2.org**

Color

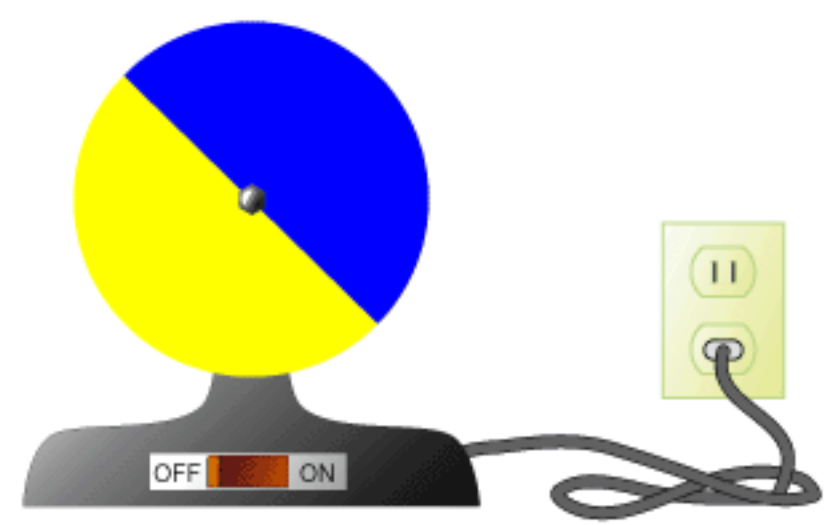
- The principles behind the effective use of color to represent data were developed over the course of more than a century of work by cartographers, and refined by researchers in perception. Issues that complicate color choices:
  - The relationship between the light we see and the colors we perceive is extremely complicated.
  - There are multiple types of data, each suited to a different color scheme.
  - A significant number of people (mostly men), are color blind.
  - Arbitrary color choices can be confusing for viewers unfamiliar with a data set.
  - Light colors on a dark field are perceived differently than dark colors on a bright field, which can complicate some visualization tasks, such as target detection.

Color: The RGB (CMY) Color Model

- **RGB: Additive Colors**
  - **Is produced by any combination of solid spectral colors that are optically mixed by being placed closely together, or by being presented in very rapid succession. Under these circumstances, two or more colors may be perceived as one color.**

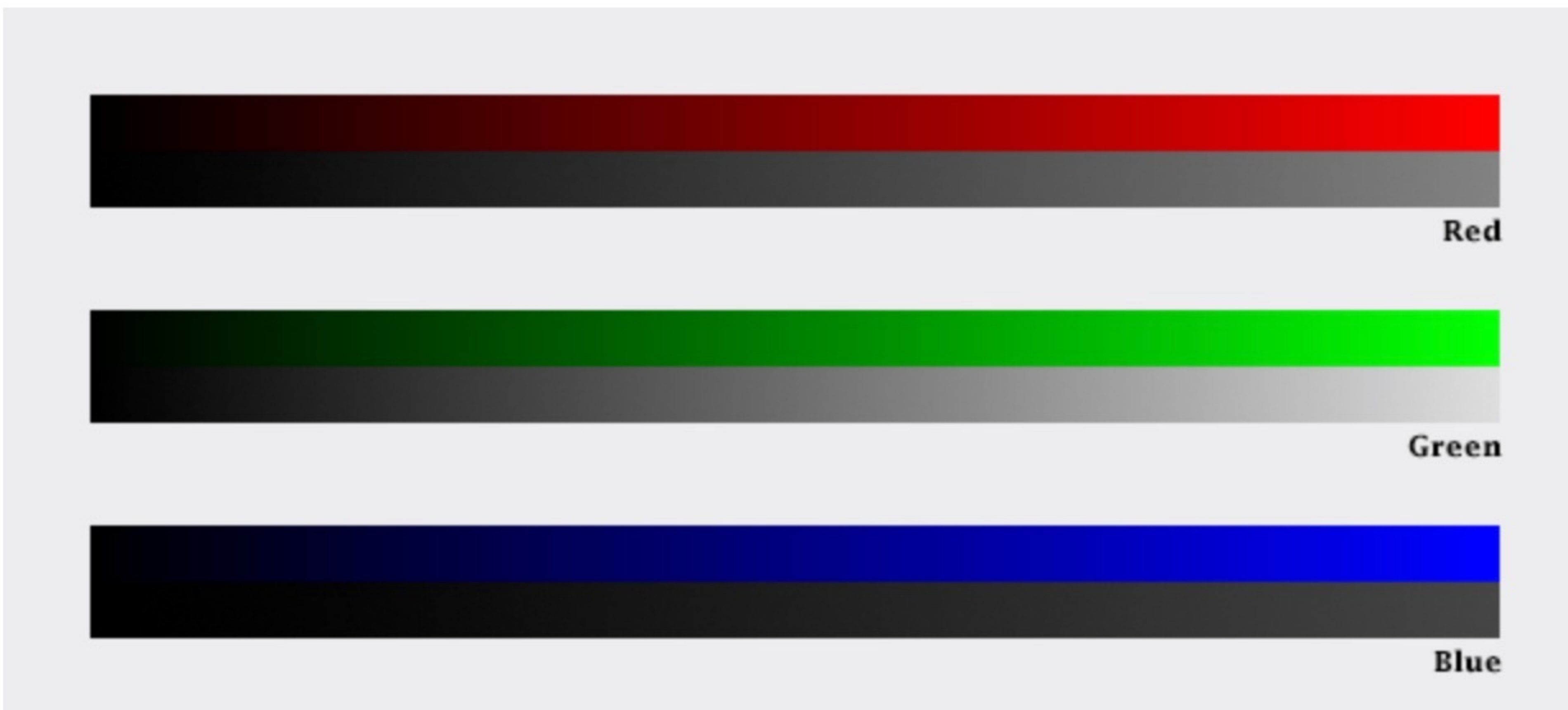


The **secondary colors of RGB**, **cyan**, **magenta**, and **yellow**, are formed by the mixture of two of the primaries and the exclusion of the third



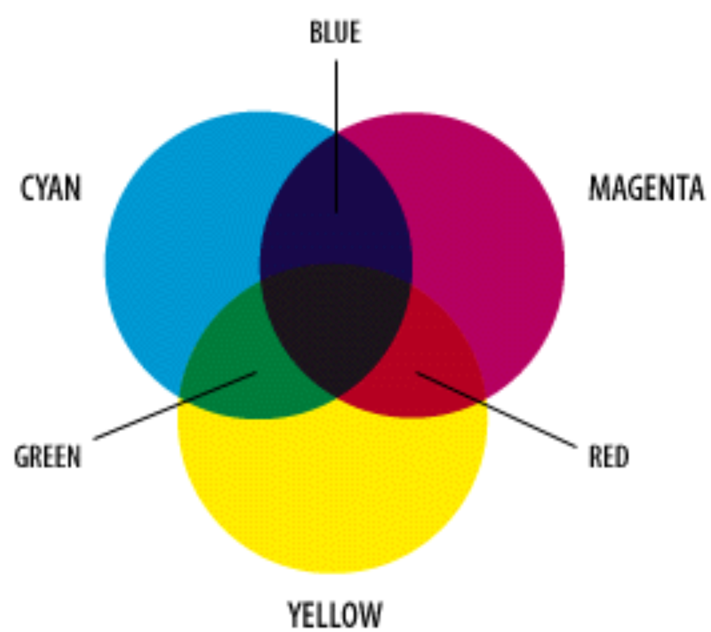
Color: The RGB (CMY) Color Model

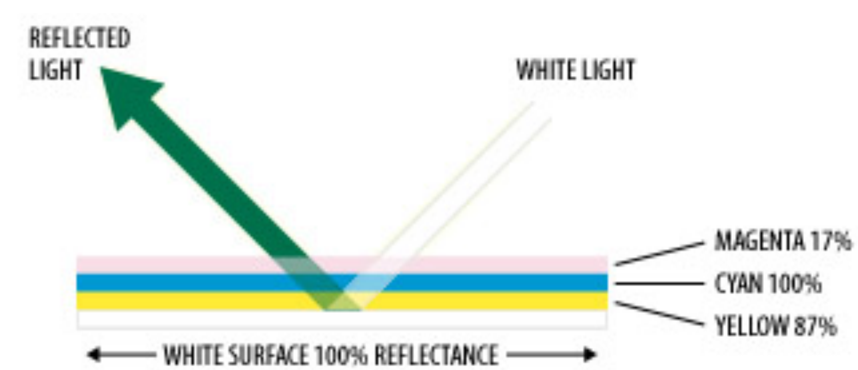
- **Computers calculate color using the RGB model. Unfortunately, we see green as brighter than red, which itself is brighter than blue, so colors specified in terms a computer understands (RGB intensities from 0-255) don't always translate well to how we see.**



Color: The RGB (CMY) Color Model

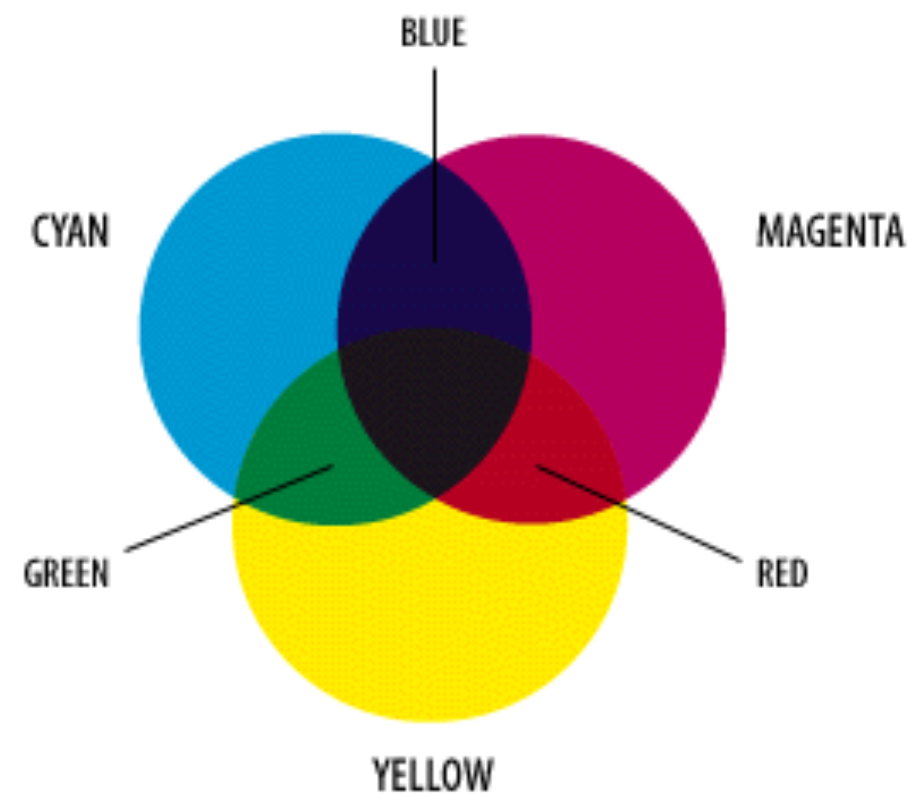
- **CMY(K): Subtractive Colors**
  - **Subtractive colors are seen when pigments in an object absorb certain wavelengths of white light while reflecting the rest.**
  - **They correspond roughly to the primary colors in art production**





Color: The RGB and the CMY Color Models

- **Colors from CMY(K) are different from RGB colors**
  - **Just as the primary colors of CMY are the secondary colors of RGB,**
  - **The primary colors of RGB are the secondary colors of CMY.**
  - **The colors created by the subtractive model of CMY don't look exactly like the colors created in the additive model of RGB.**
  - **Particularly, CMY cannot reproduce the brightness of RGB colors.**

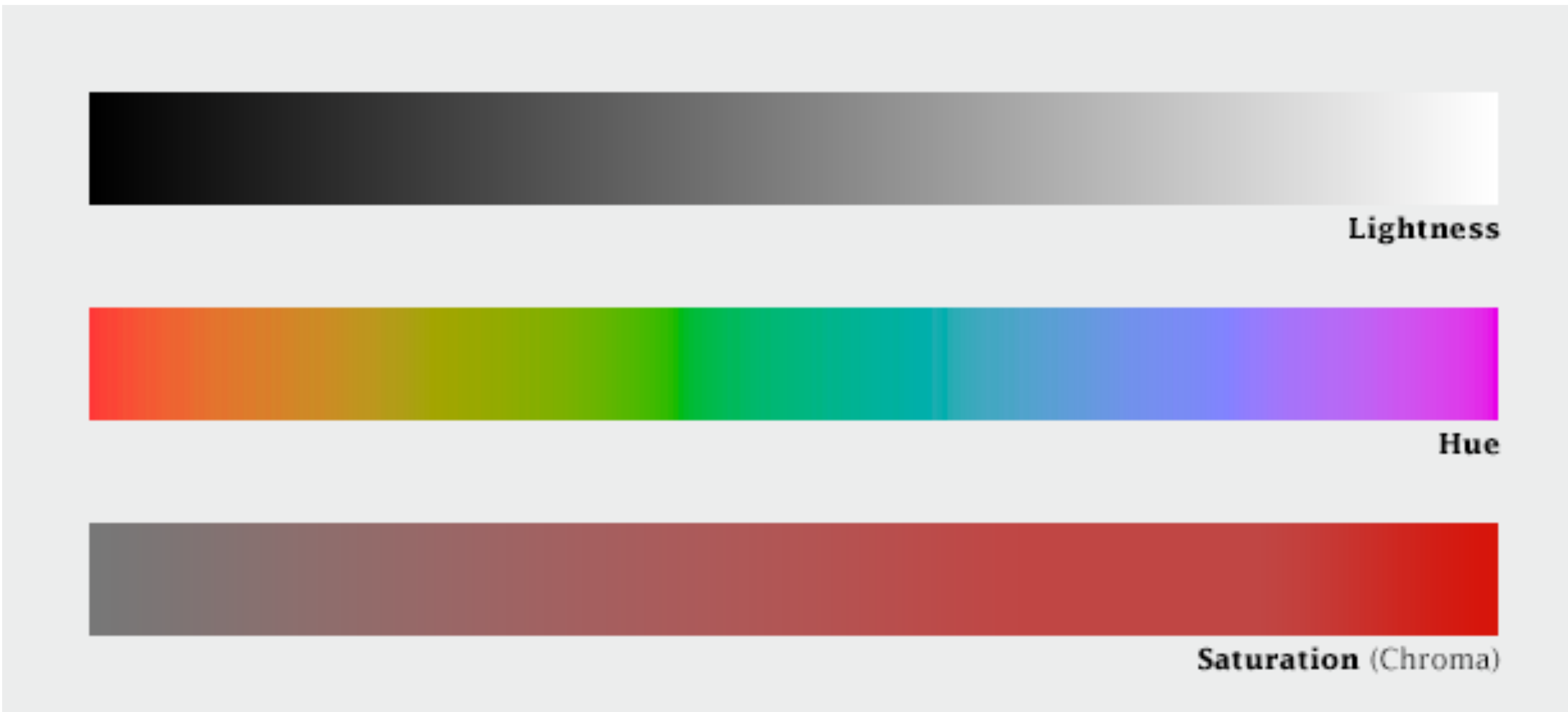


Color: Munsell's model

- Although our eyes see color through retinal cells that detect red, green, and blue light, we don't think in RGB.
- Rather, we think about color in terms of
  - lightness (black to white);
  - hue (red, orange, yellow, green, blue, indigo, violet);
  - saturation (dull to brilliant).
- These three variables (originally defined by Albert H. Munsell) are the foundation of any color system based on human perception.

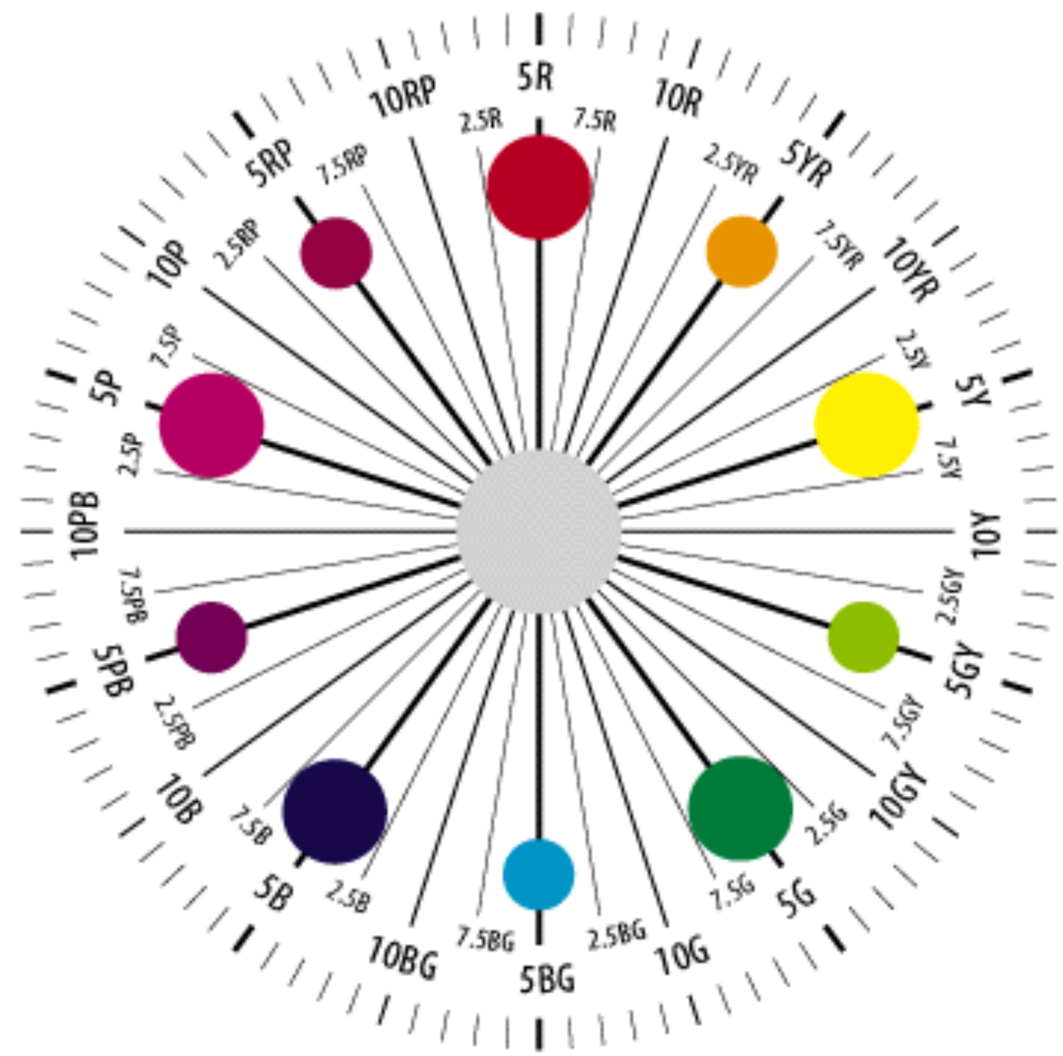
Color: Munsell's model

- **Lightness, hue, and saturation (sometimes called chroma)**



Color: Munsell's model - Hue

- **Hue** as "**the quality by which we distinguish one color from another.**"
- **He selected five principle colors: red, yellow, green, blue, and purple; and five intermediate colors: yellow-red, green-yellow, blue-green, purple-blue, and red-purple;**
- **They are arranged in a wheel measured off in 100 compass points;**
- **Each primary and intermediate color was allotted ten degrees**



Color: Munsell's model - lightness

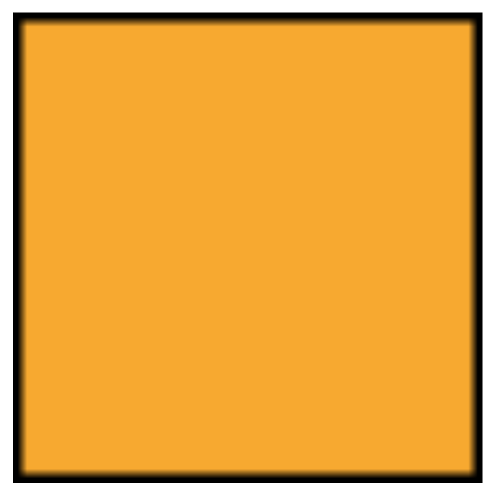
- **Lightness** (or Value) as "**the quality by which we distinguish a light color from a dark one**." It is a neutral axis that refers to the grey level of the color. This ranges from white to black.

- The notation N is used to denote the gray value at any point on the axis: values of 0 (black) through 10 (white).

- Munsell's **scale of lightness** (or value) is **visual, or perceptual**. That is, it's based on how we see differences in relative light, not on a strict set of mathematical values from a light source or illuminant

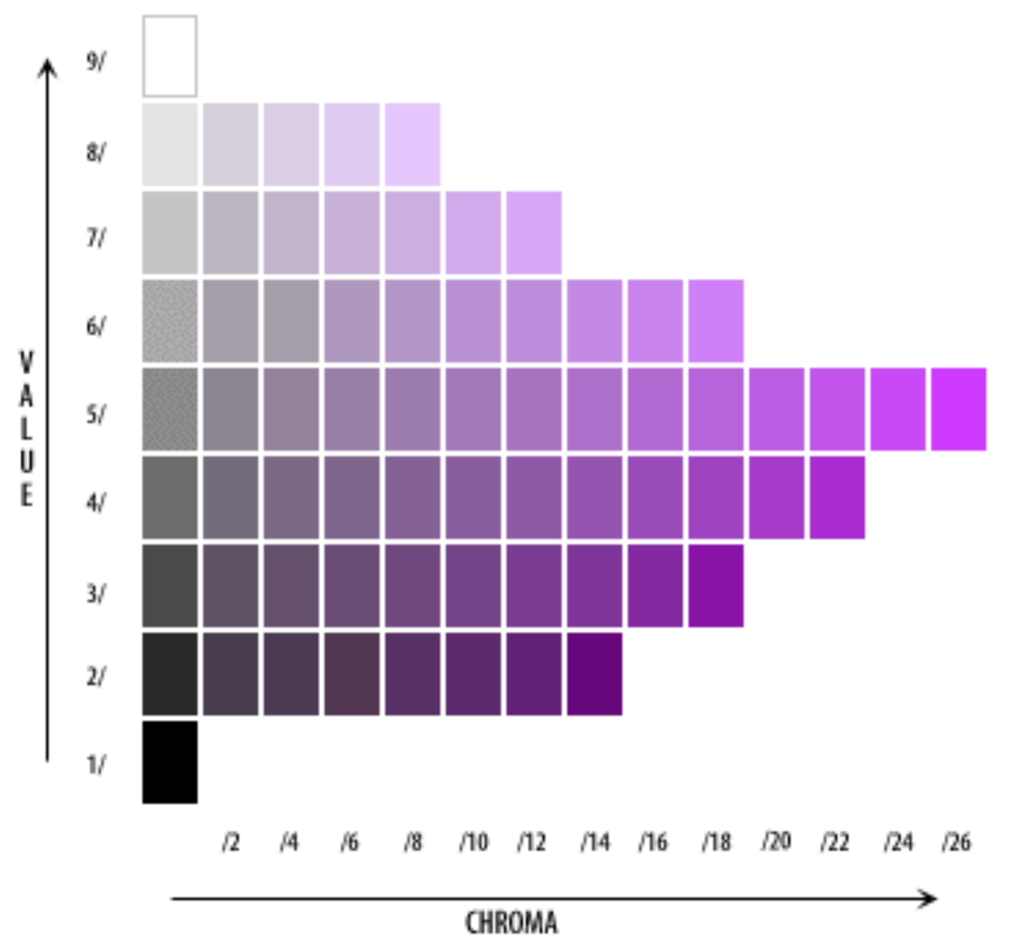
Color: Munsell's model - Saturation (or Croma)

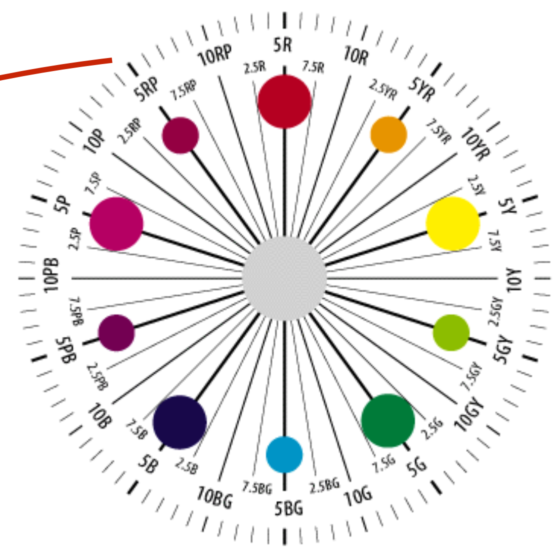
- **Chroma is the quality that distinguishes the difference from a pure hue to a gray shade.**
- **Thus 7.5YR 7/12 indicates a yellow-red hue tending toward yellow with a Value (lightness) of 7 and a chroma of 12:**



Color: Munsell's model - Saturation (or Croma)

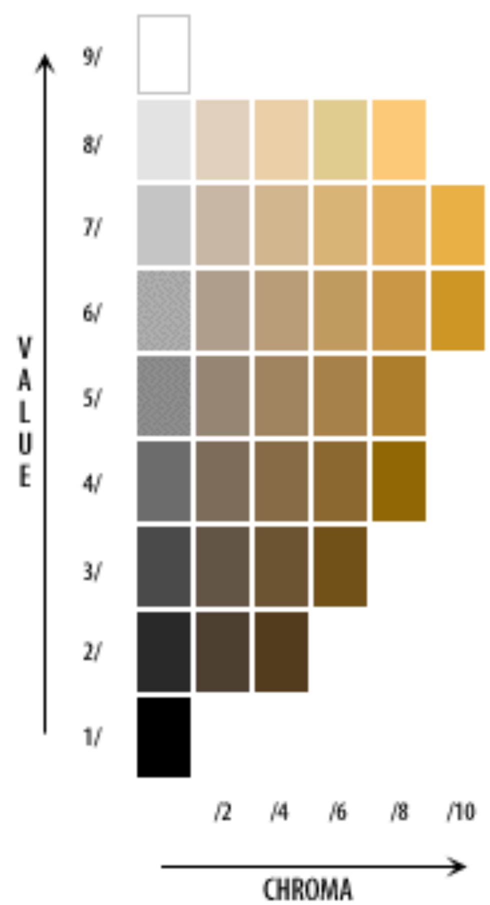
- **Chroma is not uniform for every hue at every value (lightness).**
- **Munsell saw that full chroma for individual hues might be achieved at very different places in the color sphere. For example, the fullest chroma for hue 5RP (red-purple) is achieved at 5/26:**

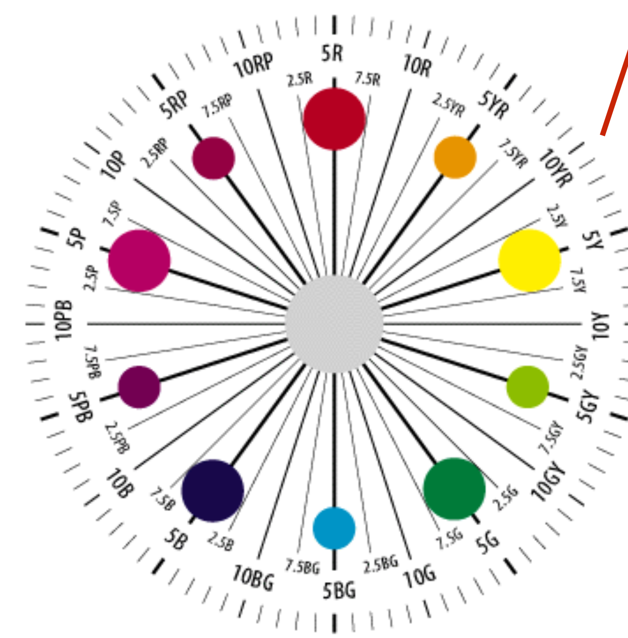




Color: Munsell's model - Saturation (or Croma)

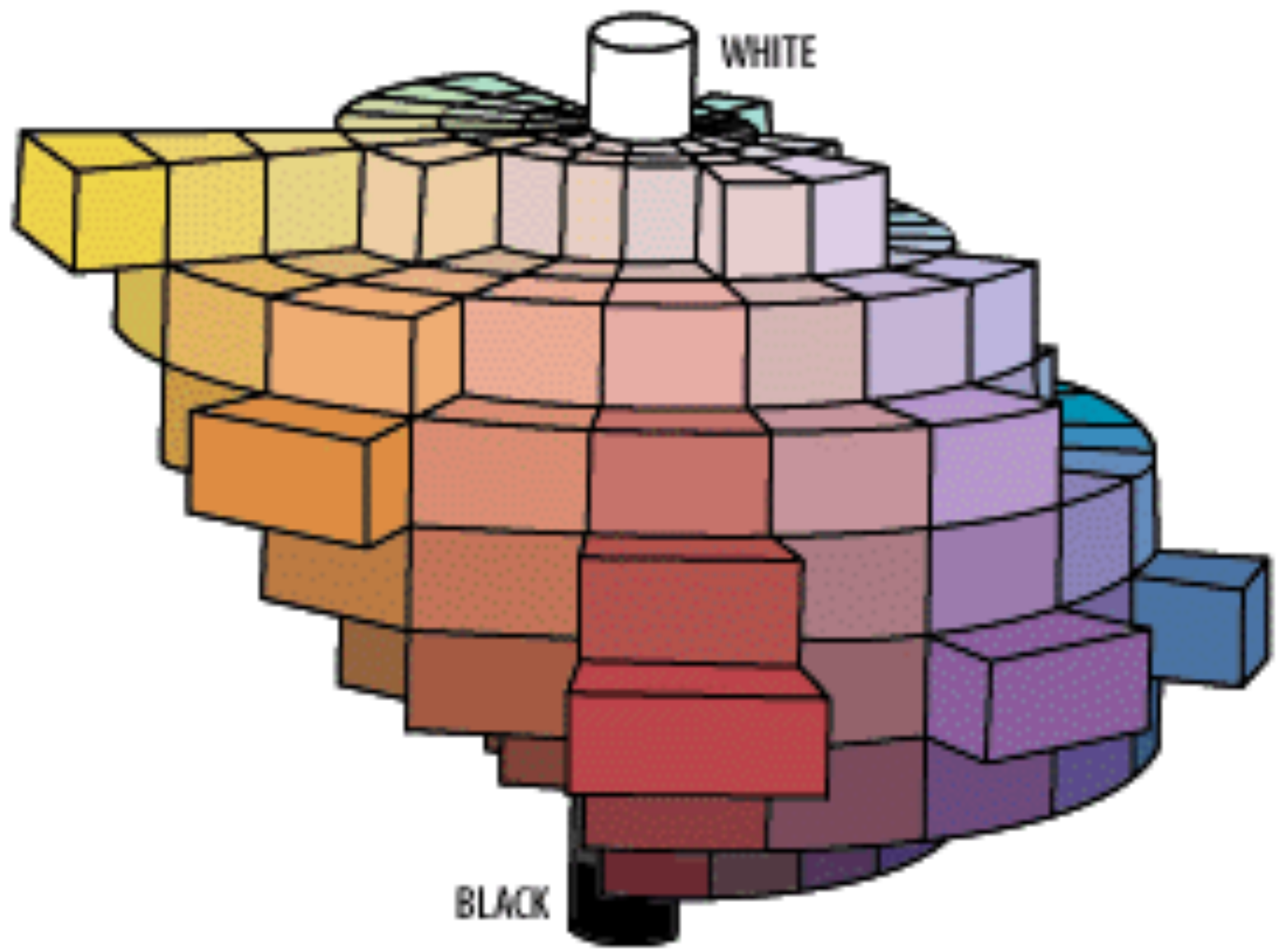
- **Chroma is not uniform for every hue at every value (lightness).**
- **Another color such as 10YR (yellowish yellow-red) has a much shorter chroma axis and reaches fullest chroma at 7/10 and 6/10:**





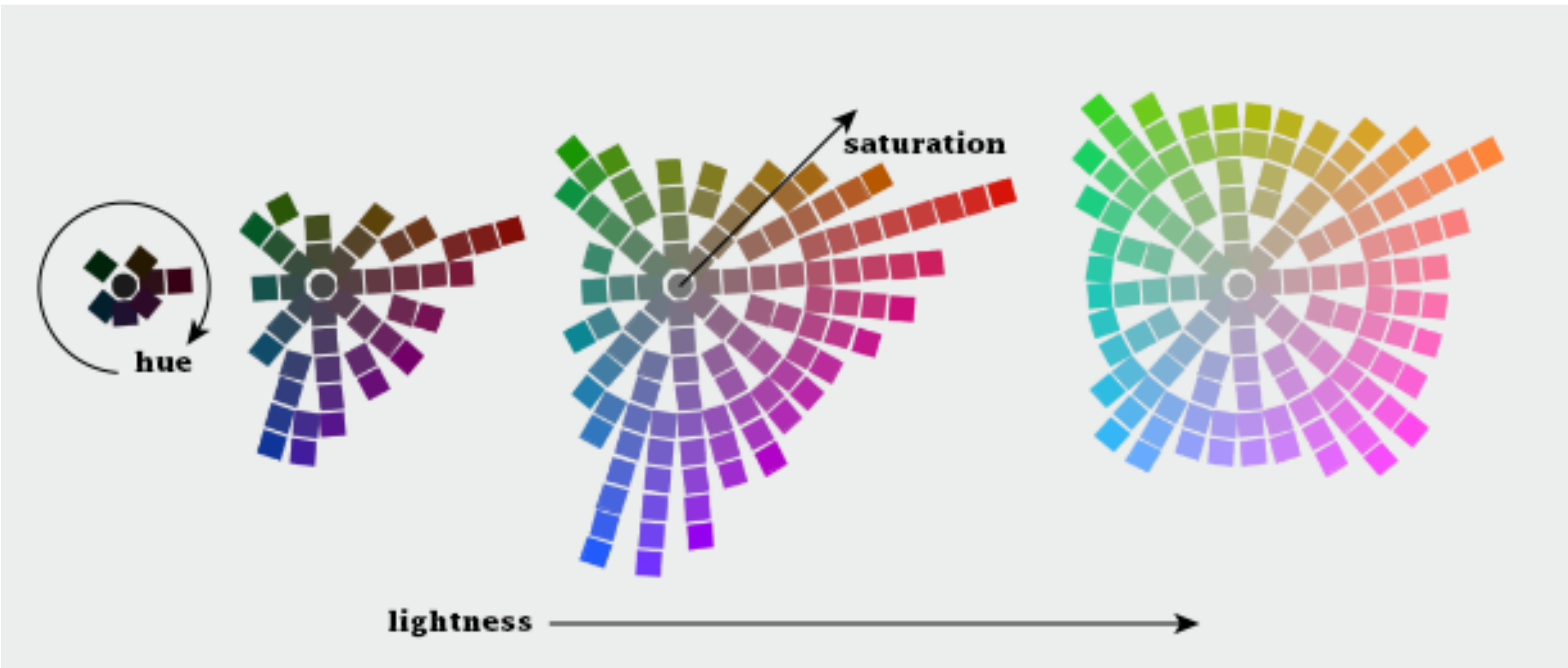
Color: Munsell's model - Saturation (or Croma)

- **A three-dimensional solid representation of Munsell's system would look like the following:**



Color: Munsell's model - Saturation (or Croma)

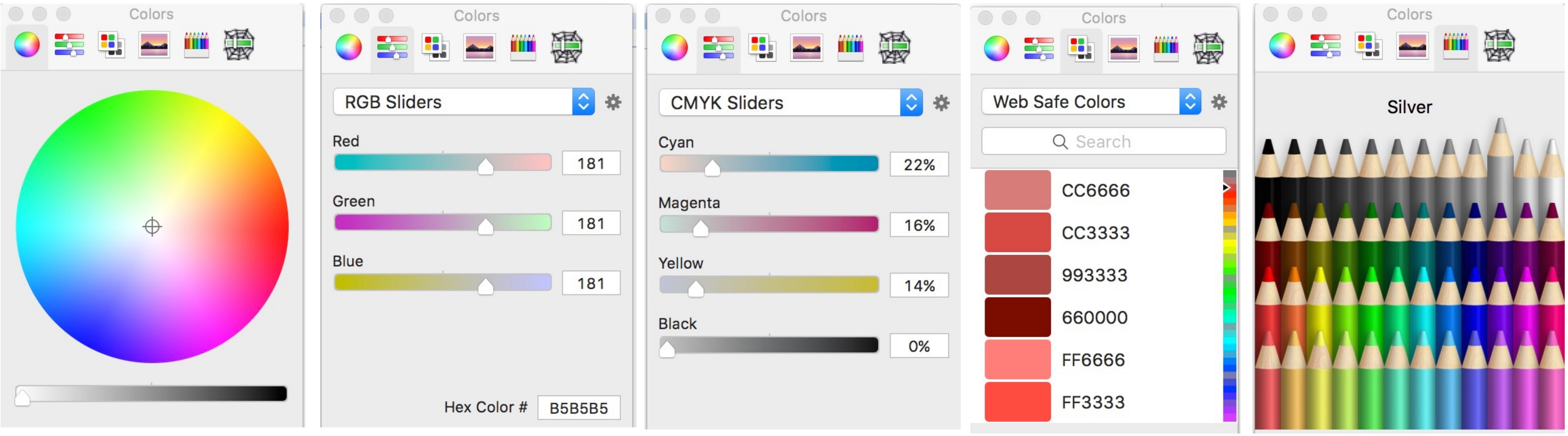
- **Projections of three-dimensional solid representation of Munsell's system would look like the following:**

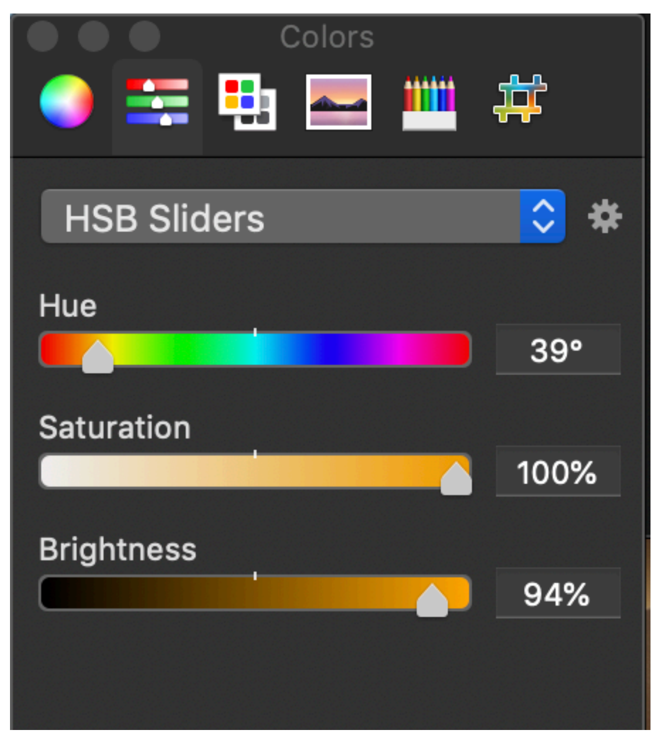


Color: Other color models

- **Color perception was mapped by the International Commission on Illumination (CIE - Commission Internationale de l´Eclairage in French):**
  - **CIE L*a*b, for example, is used internally by Adobe Photoshop to interpolate color gradients and convert images from RGB (screen) to CMYK (print).**
  - **CIE L*C*h [lightness, chroma (saturation), hue]**

Color: pickup colors





Color: perceptual models - Goals

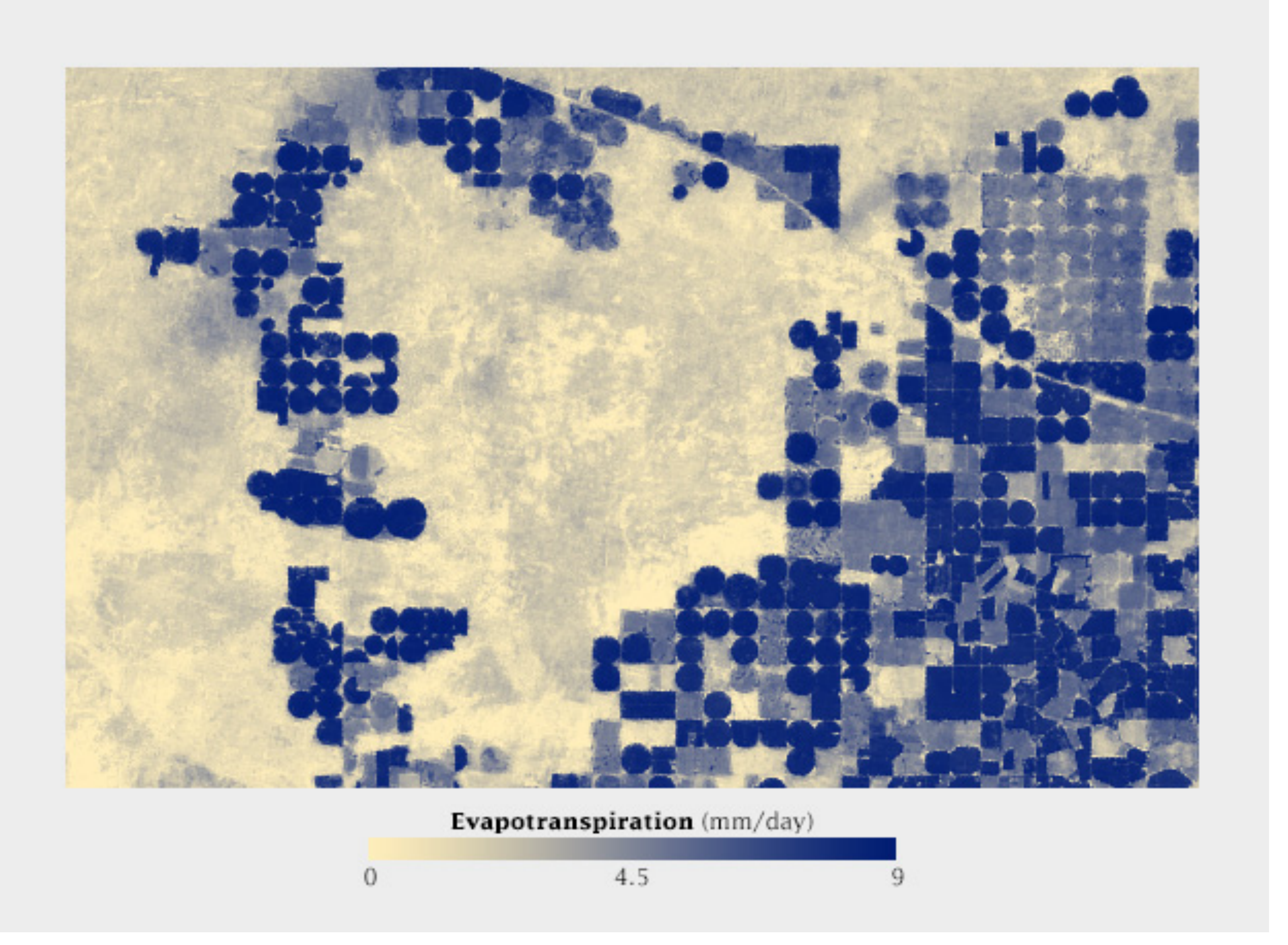
- To control the difference viewers perceive between different colors, as opposed to the distance between their positions in RGB space.
  - Perceptual balance. A unit step anywhere along the color scale produces a perceptually uniform difference in color.
  - Distinguishability. Within a discrete collection of colors, every color is equally distinguishable from all the others (i.e., no specific color is “easier” or “harder” to identify).
  - Flexibility. Colors can be selected from any part of color space (e.g., the selection technique is not restricted to only greens, or only reds and blues).

Color: **select a color map** for a **target data attribute**

- **Properties of the attribute, such as its spatial frequency, its continuous or discrete nature, and the type of analysis to be performed, are used to choose an appropriate color representation.**

- **Most common cases**
  - **Sequential Data**
  - **Divergent Data**
  - **Qualitative data**

Color: Sequential Data



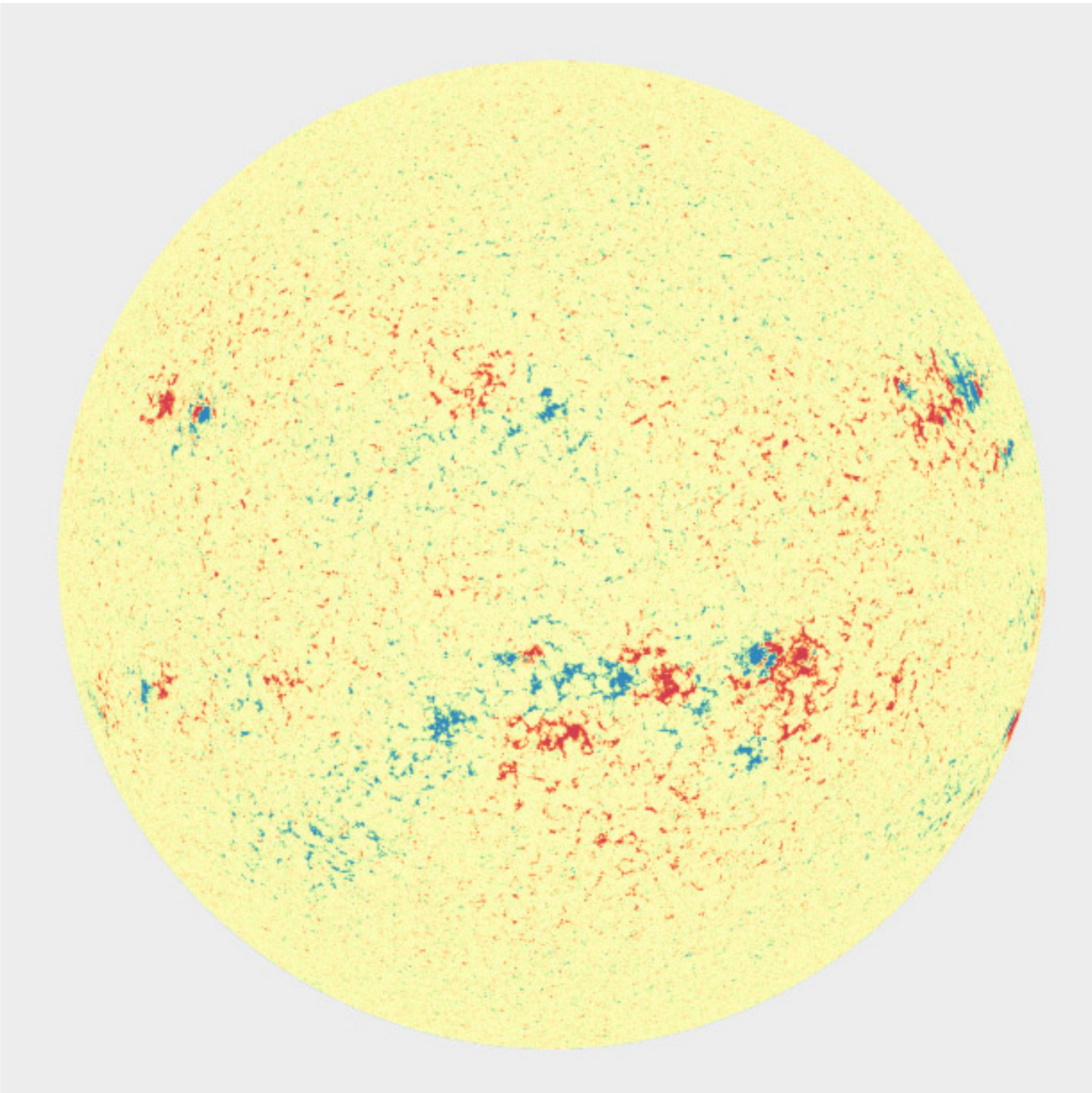
Sequential data lies along a smooth continuum, and is suited to a palette with a linear change in lightness, augmented by simultaneous shifts in hue and saturation.

Color: Divergent Data

- **Data that varies from a central value (or other breakpoint) is known as divergent or bipolar data.**
  - **(Ex: profits and losses; differences from the norm (daily temperature compared to the monthly average); change over time.**

Divergent palettes, each composed of two sequential palettes merged with a neutral color. (Derived from the NASA Ames Color Tool (top) and Color Brewer.)

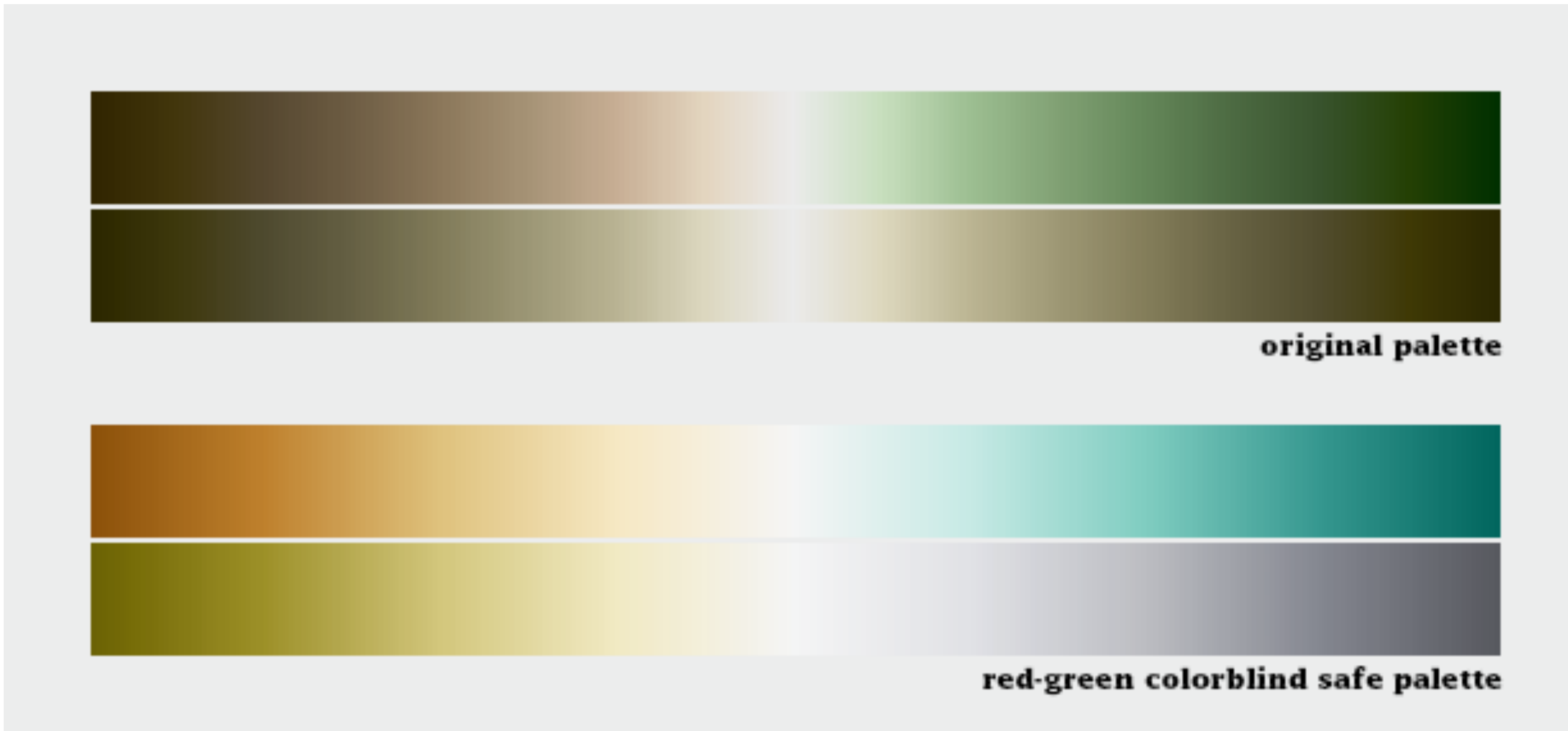
Color: Divergent Data



A magnetogram is a map of magnetic fields, in this case on the surface of the Sun.

A **divergent palette** suits this data because the north polarity (red) and south polarity (blue) are both measurements of the same quantity (magnetism), just with opposite signs

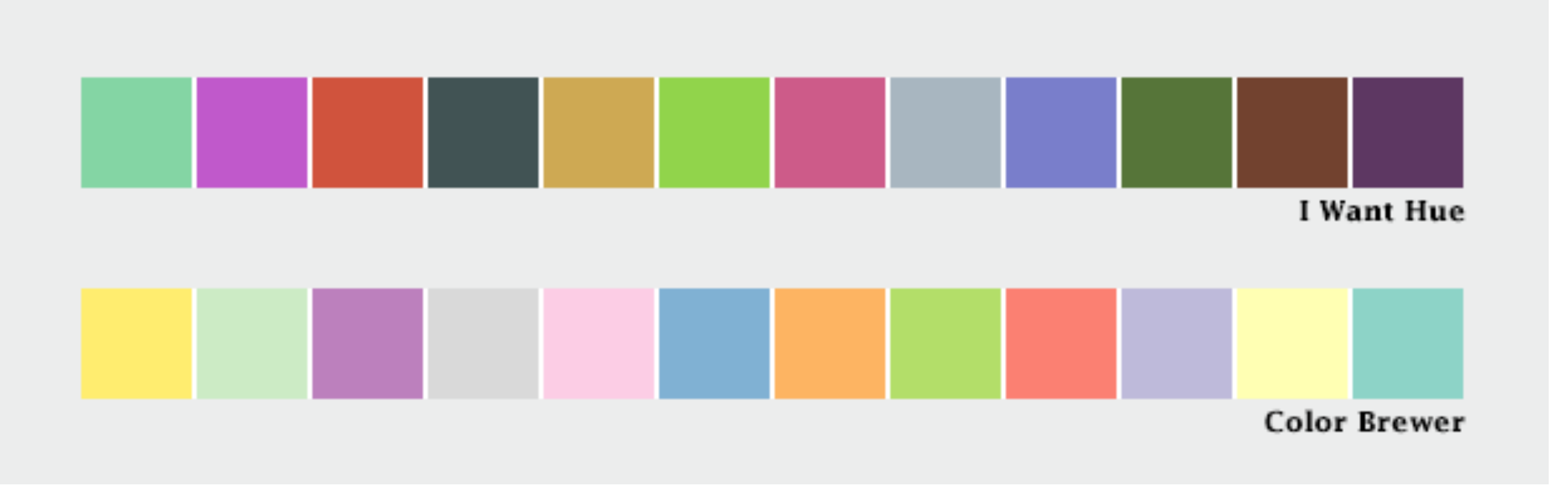
Color: Divergent Data - color blind



About 5 percent of people (almost all of them men) are color blind!

Color: Qualitative data

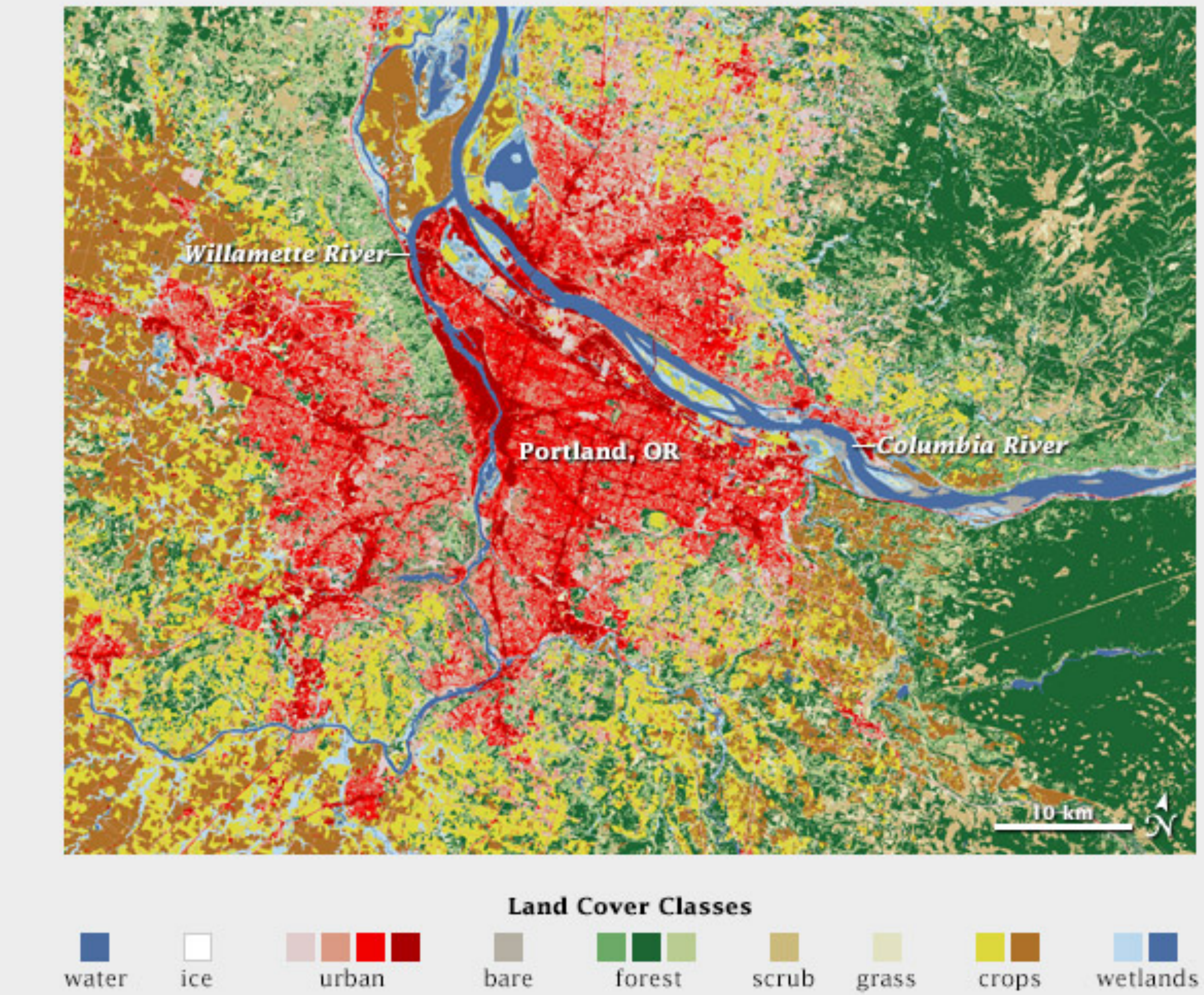
- **Qualitative data (known as categorical or thematic data) is distinct from sequential and divergent data: instead of representing proportional relationships, color is used to separate areas into distinct categories**



Color: Qualitative data - Grouped color Scheme

- **Qualitative data**

A **grouped color scheme** allows the USGS to simultaneously show **16 different land cover classes** in a single map of the area surrounding Portland, Oregon.

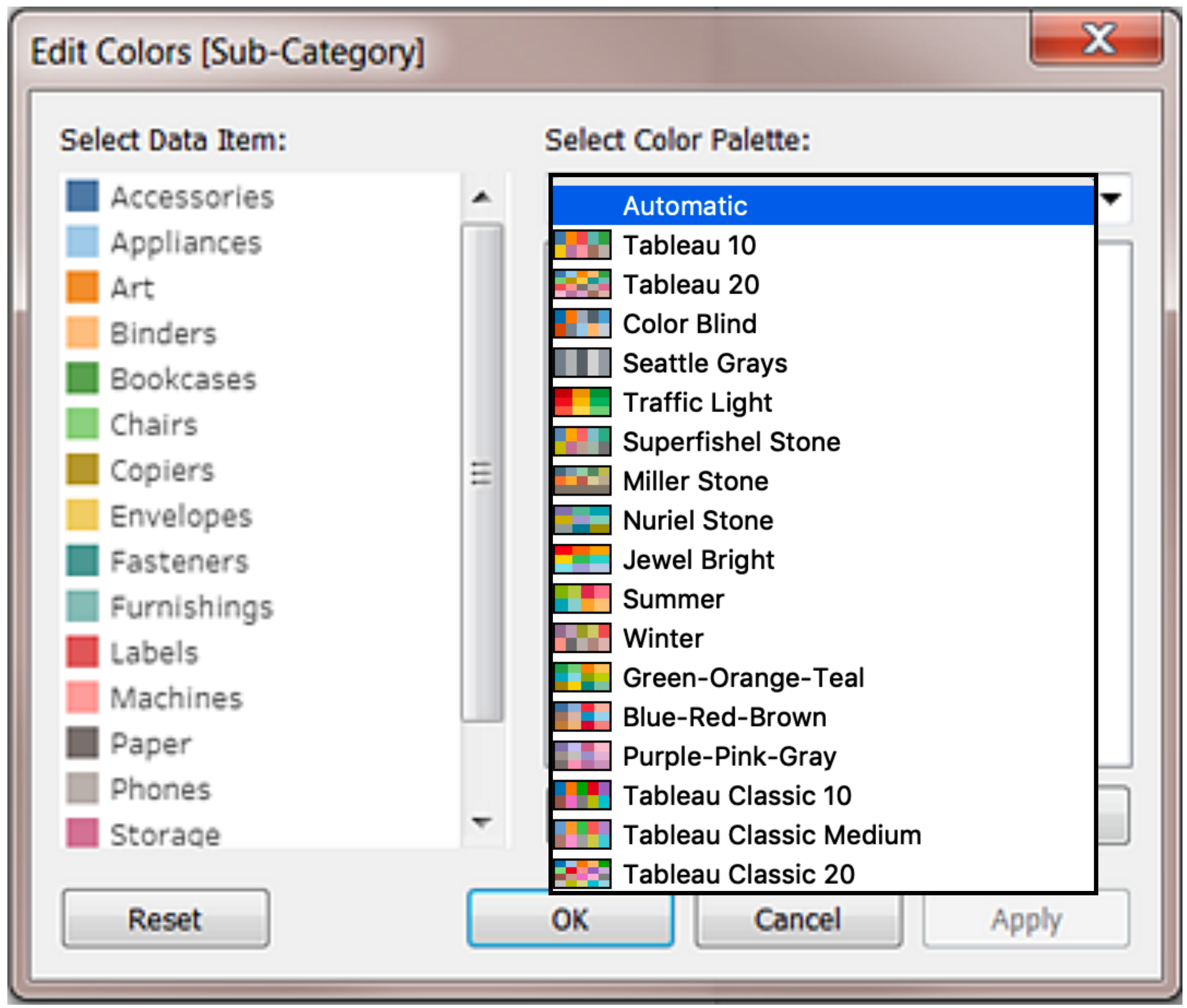


Recommended Reading (Tableau)

- **Color Palettes and Effects: https://onlinehelp.tableau.com/current/pro/desktop/en-us/viewparts_marks_markproperties_color.htm**
  - **Categorical Palettes**
  - **Quantitative Palettes**
    - Options for quantitative palettes (Stepped Color, Reversed, Use Full Color Range)
  - **Configure Color Effects**
    - Opacity
    - Mark borders
    - Mark halos
    - etc

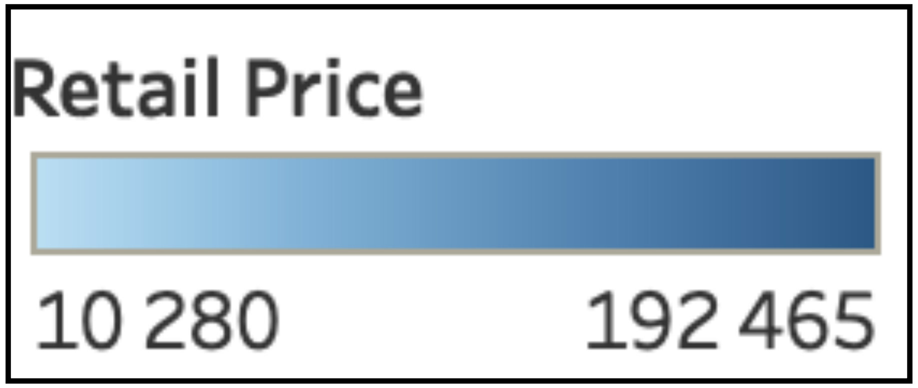
Color Palettes

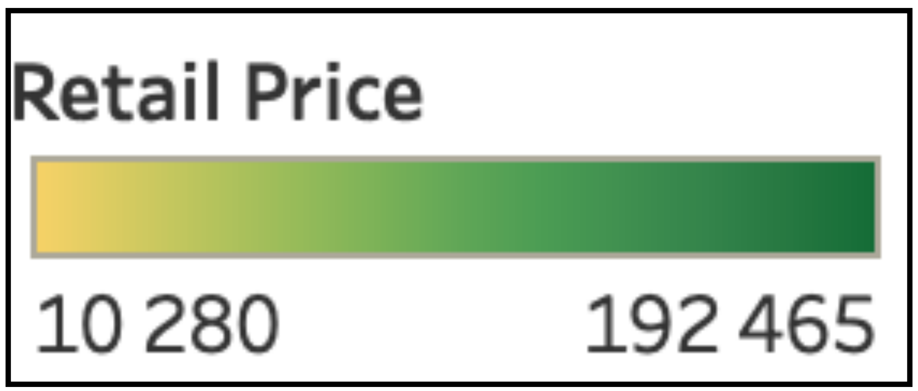
- **Categorical Palettes**

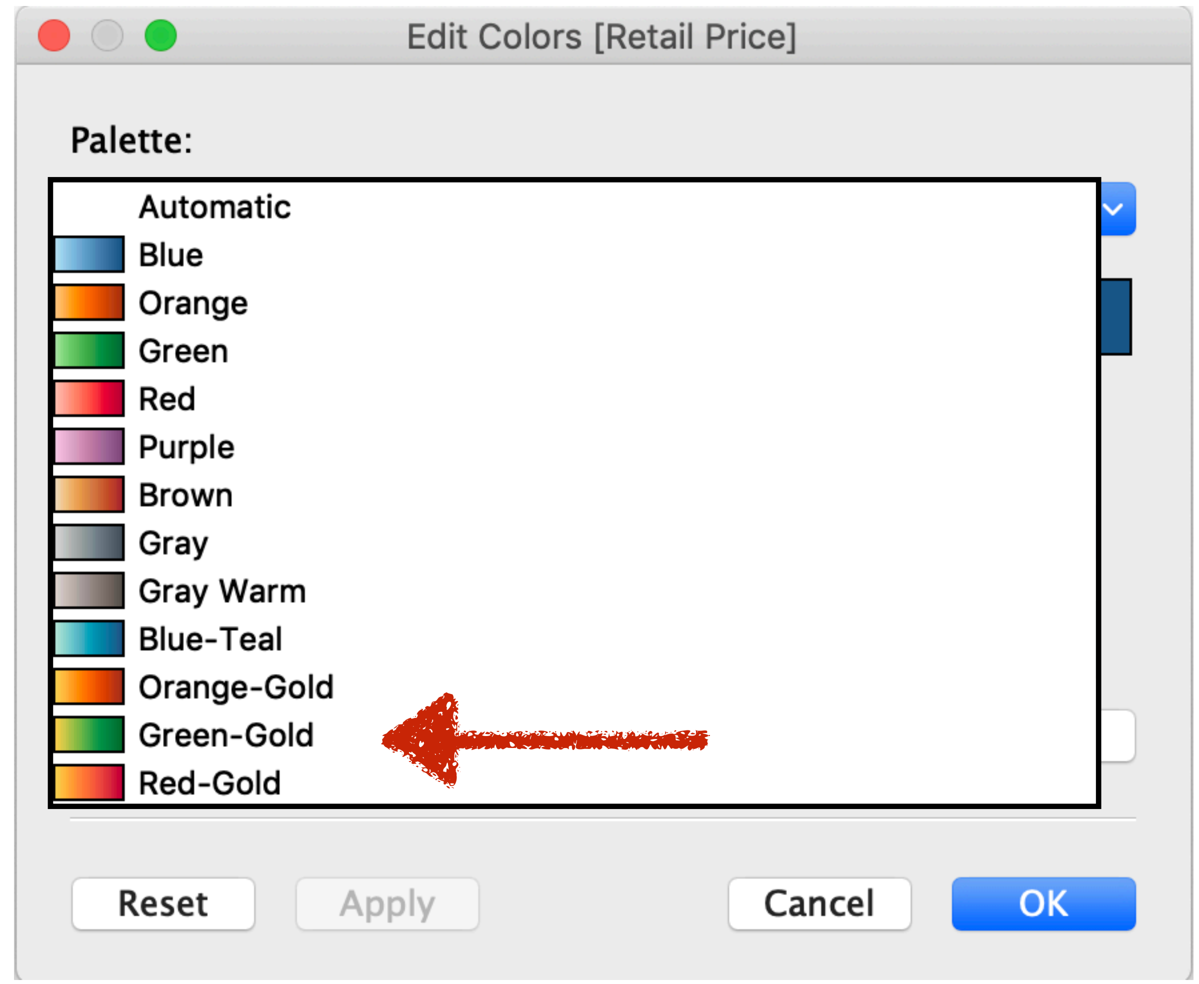


Color Palettes

- **Quantitative Palettes**

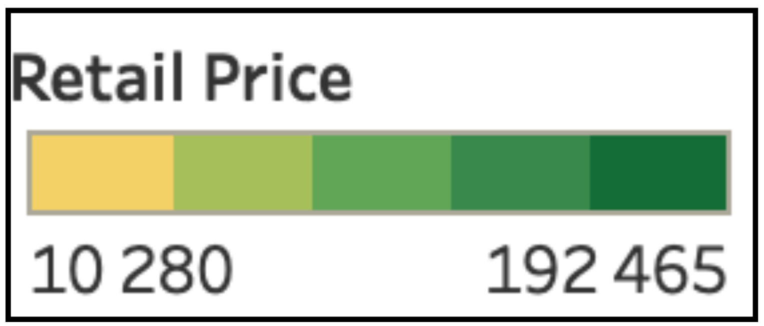


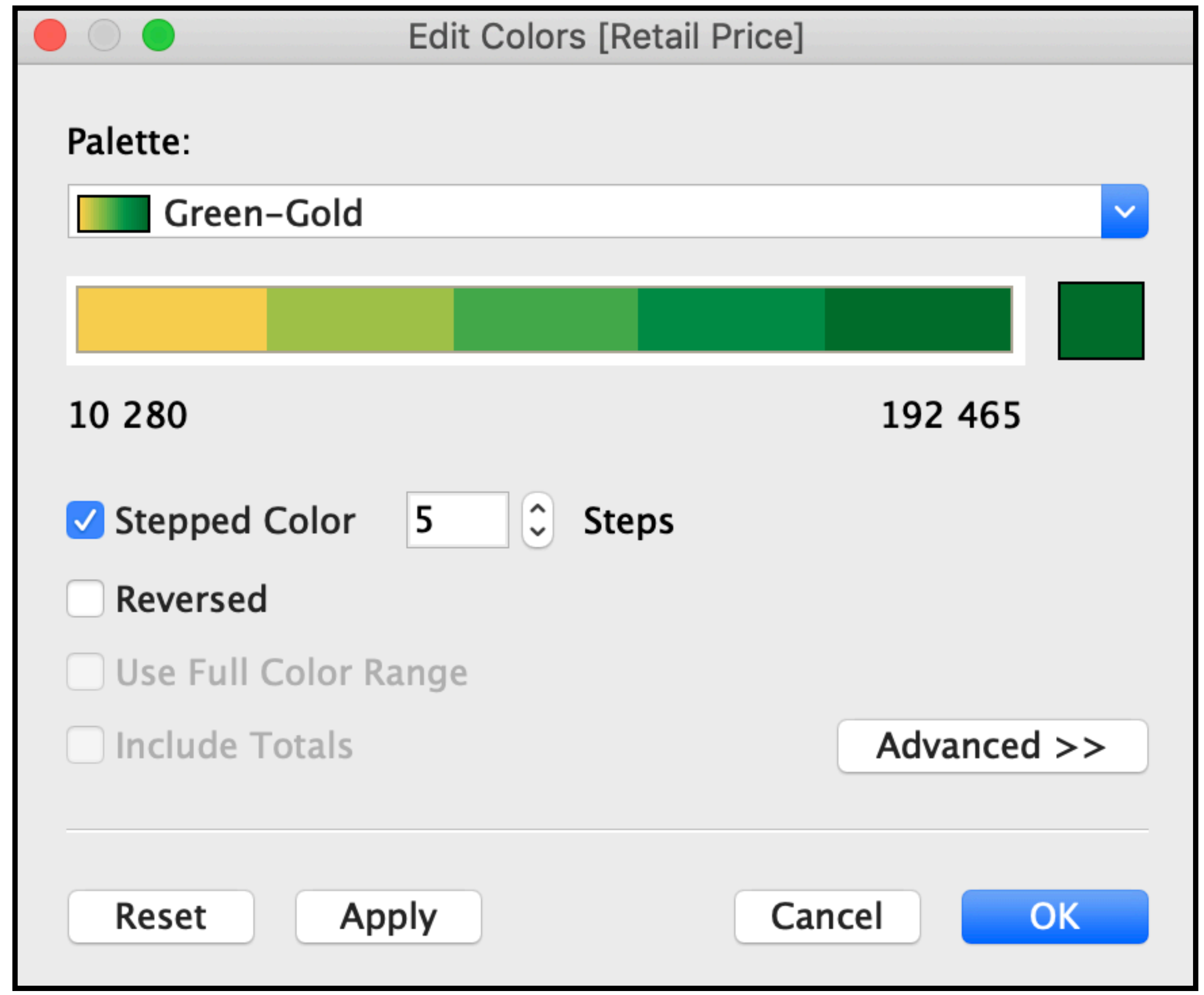




Color Palettes

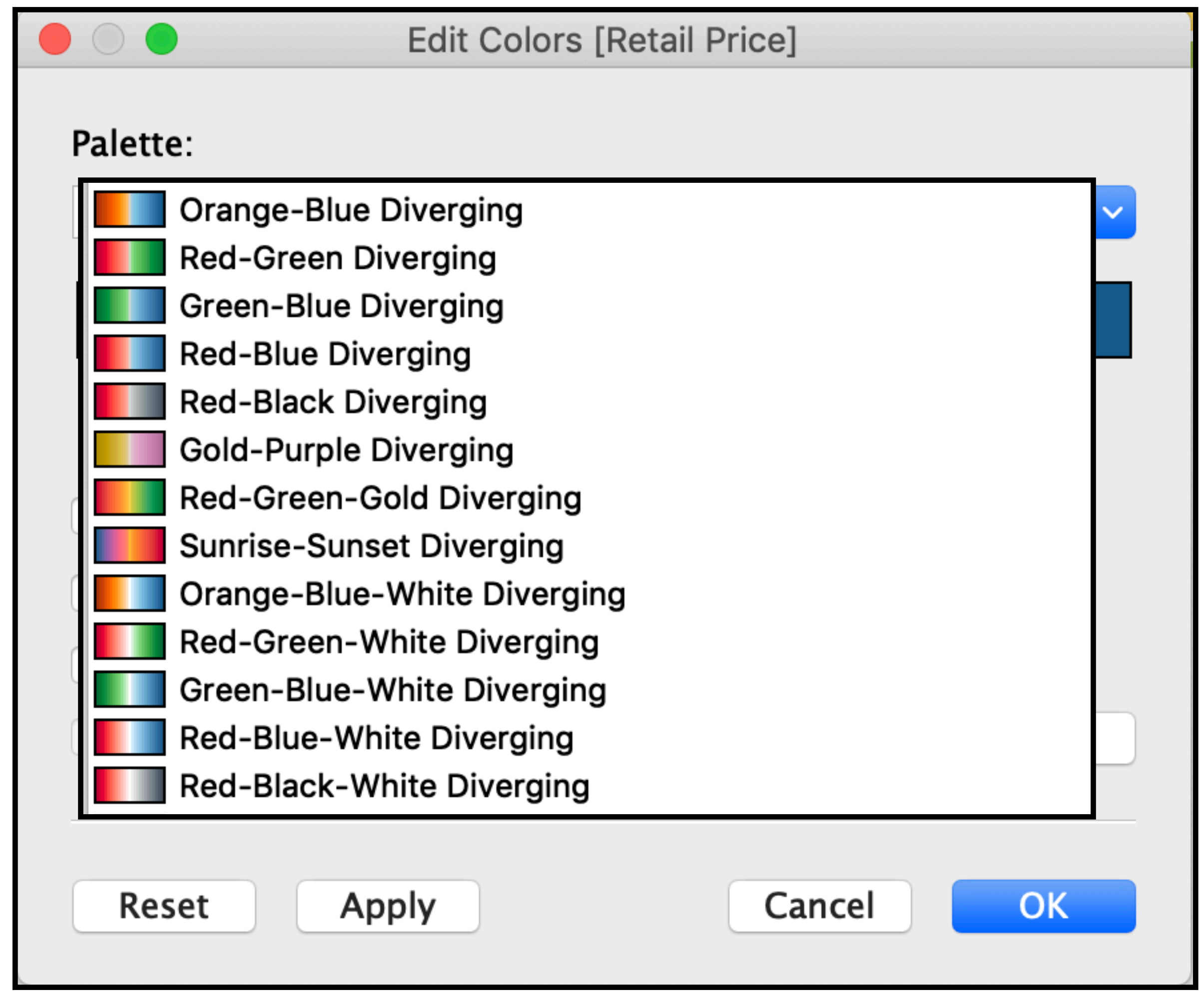
- **Quantitative Palettes**





Color Palettes

- **Quantitative Diverging Palettes**



Recommended Reading (Tableau)

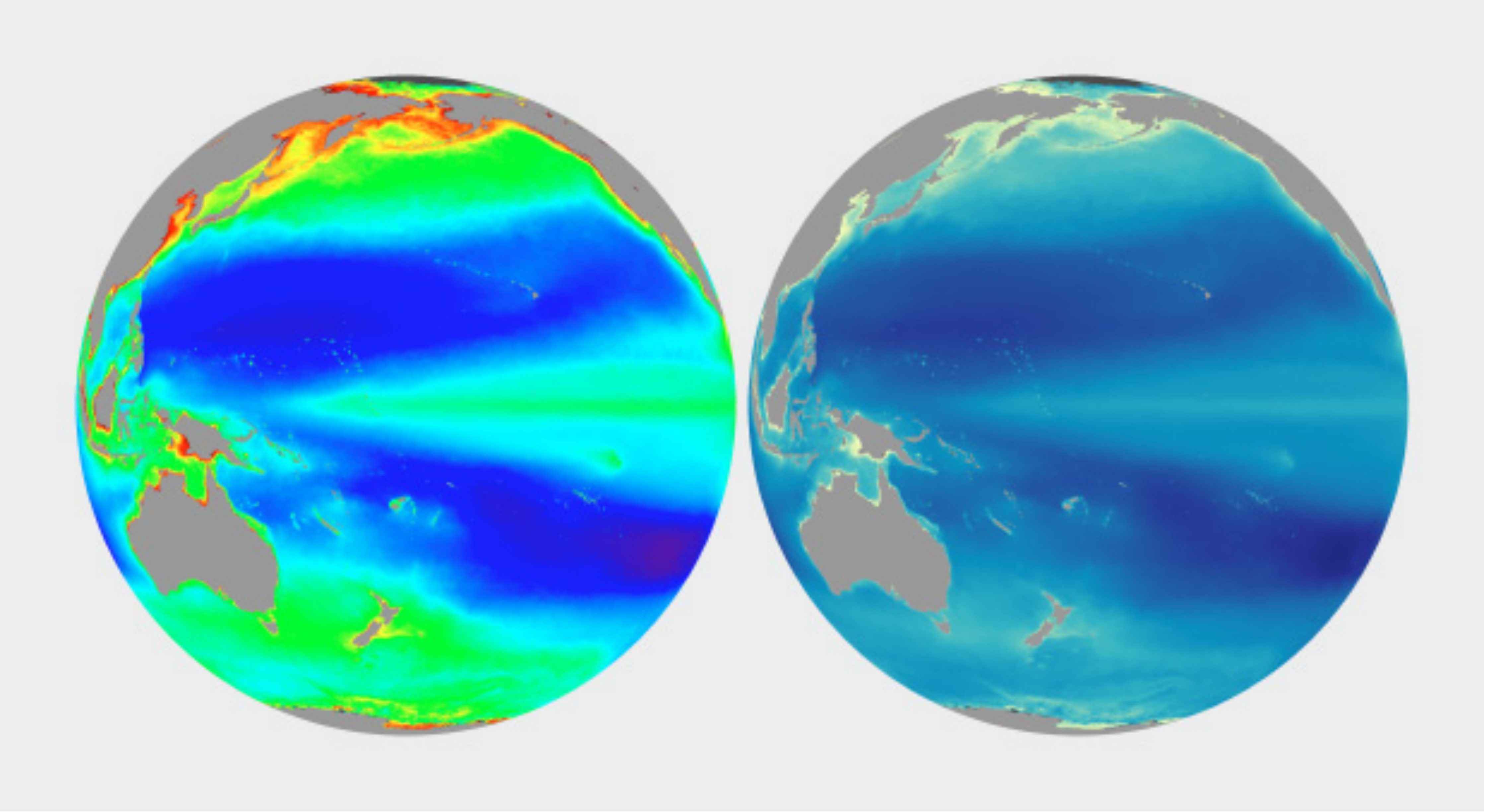
- **Color Palettes and Effects: https://onlinehelp.tableau.com/current/pro/desktop/en-us/viewparts_marks_markproperties_color.htm**
  - **Categorical Palettes**
  - **Quantitative Palettes**
    - Options for quantitative palettes (Stepped Color, Reversed, Use Full Color Range)
  - **Configure Color Effects**
    - Opacity
    - Mark borders
    - Mark halos
    - etc

Color: connecting Color to Meaning

- **This may sound obvious, but it's an underused principle. Whenever possible, make intuitive palettes.**
- **Some conventional color schemes, especially those used in scientific visualization, are difficult for non-experts to understand.**
- **Visualizations should be as easy as possible to interpret, so try to find a color scheme that matches the audience's preconceptions and cultural associations:**
  - **Vegetation is green, barren ground is gray or beige.**
  - **Water is blue. Clouds are white.**
  - **Red, orange, and yellow are hot (or at least warm); blue is chilly.**

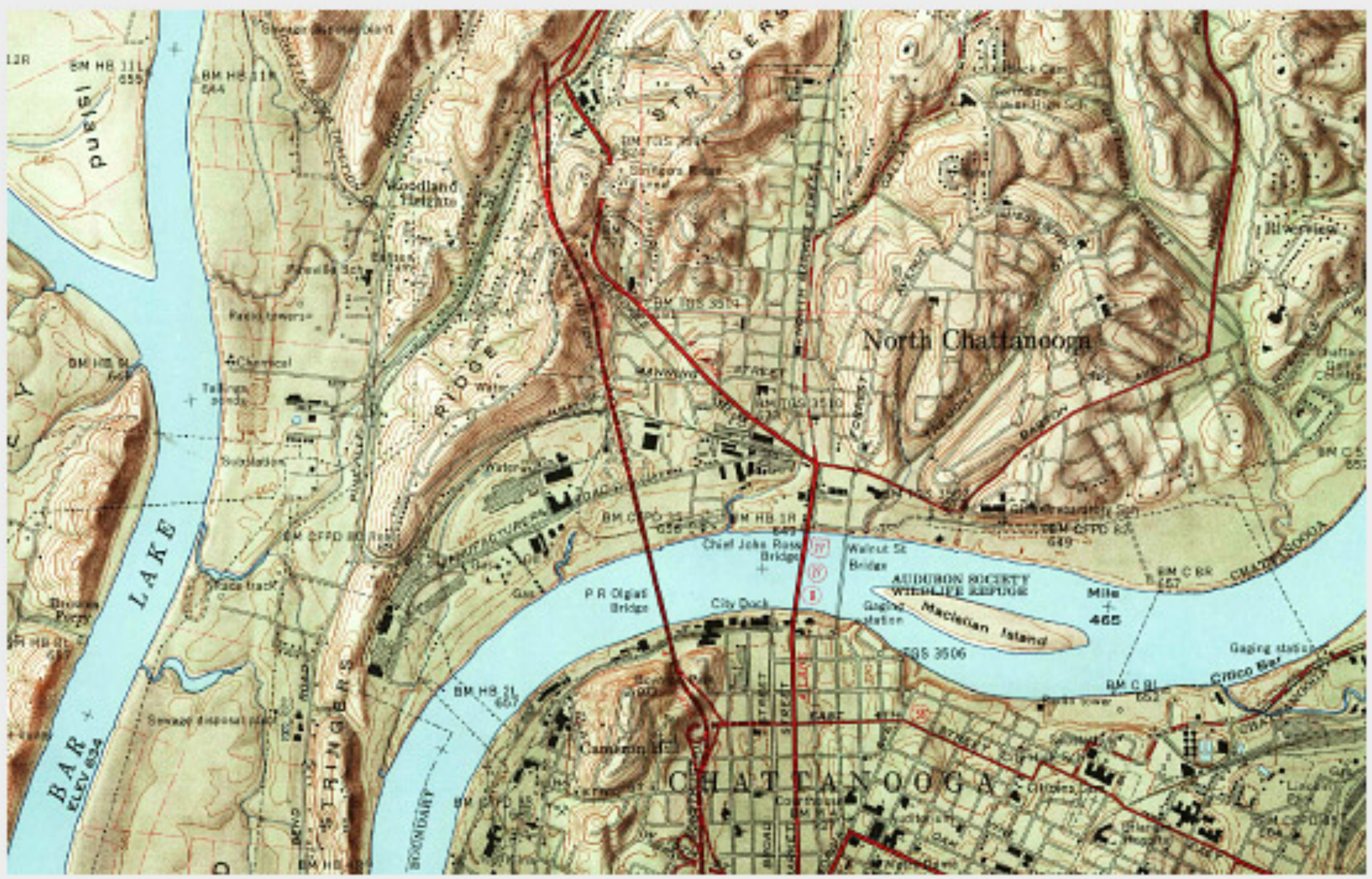
Color: connecting Color to Meaning

- **The unnatural colors of the rainbow palette (left) are often difficult for novice viewers to interpret**

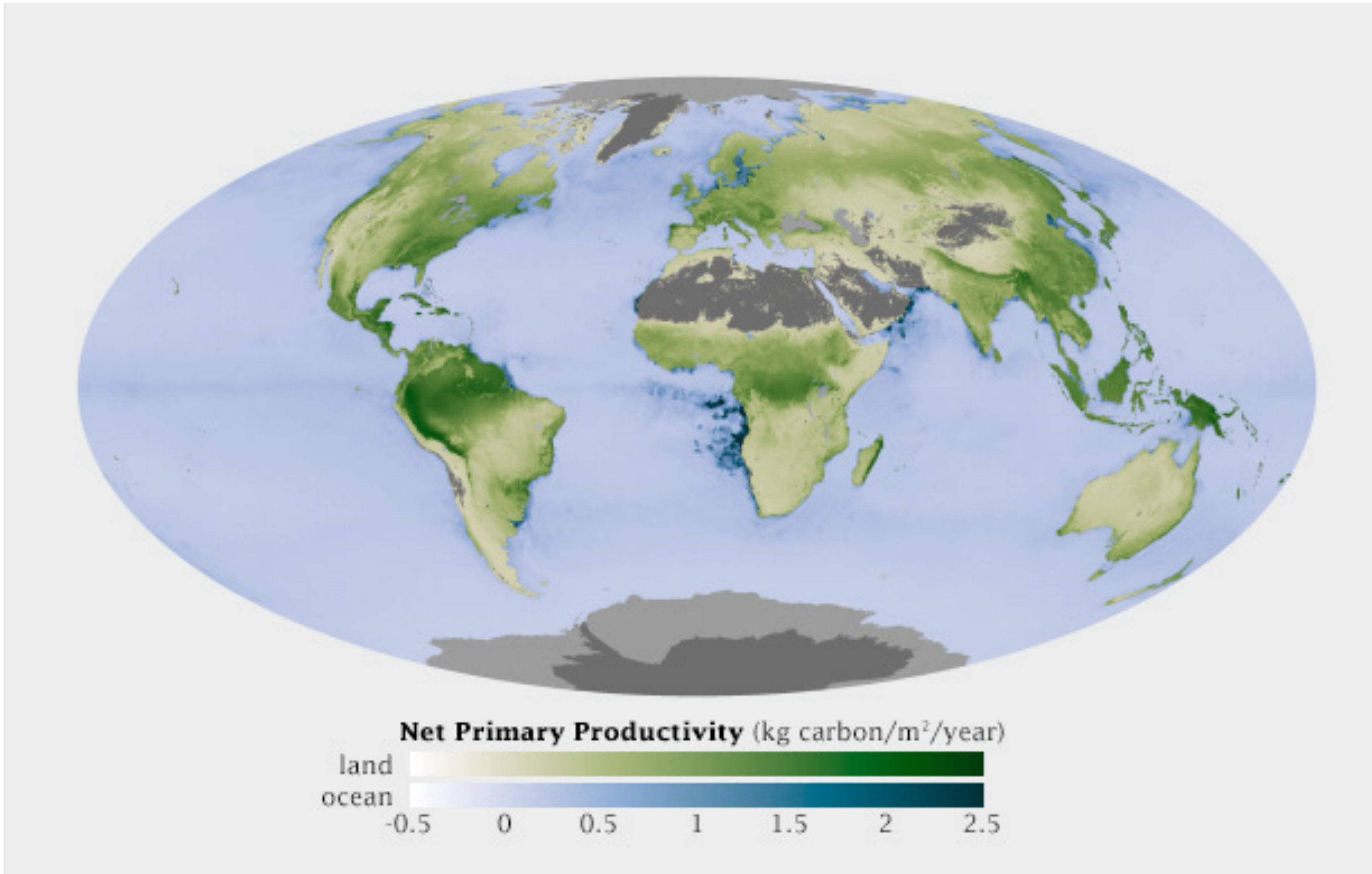


Color: Layering

- **The combination of two or more datasets often tell a story better than a single dataset, and the best visualizations tell stories. The color schemes for multiple datasets displayed together need to be designed together, and complement one another**

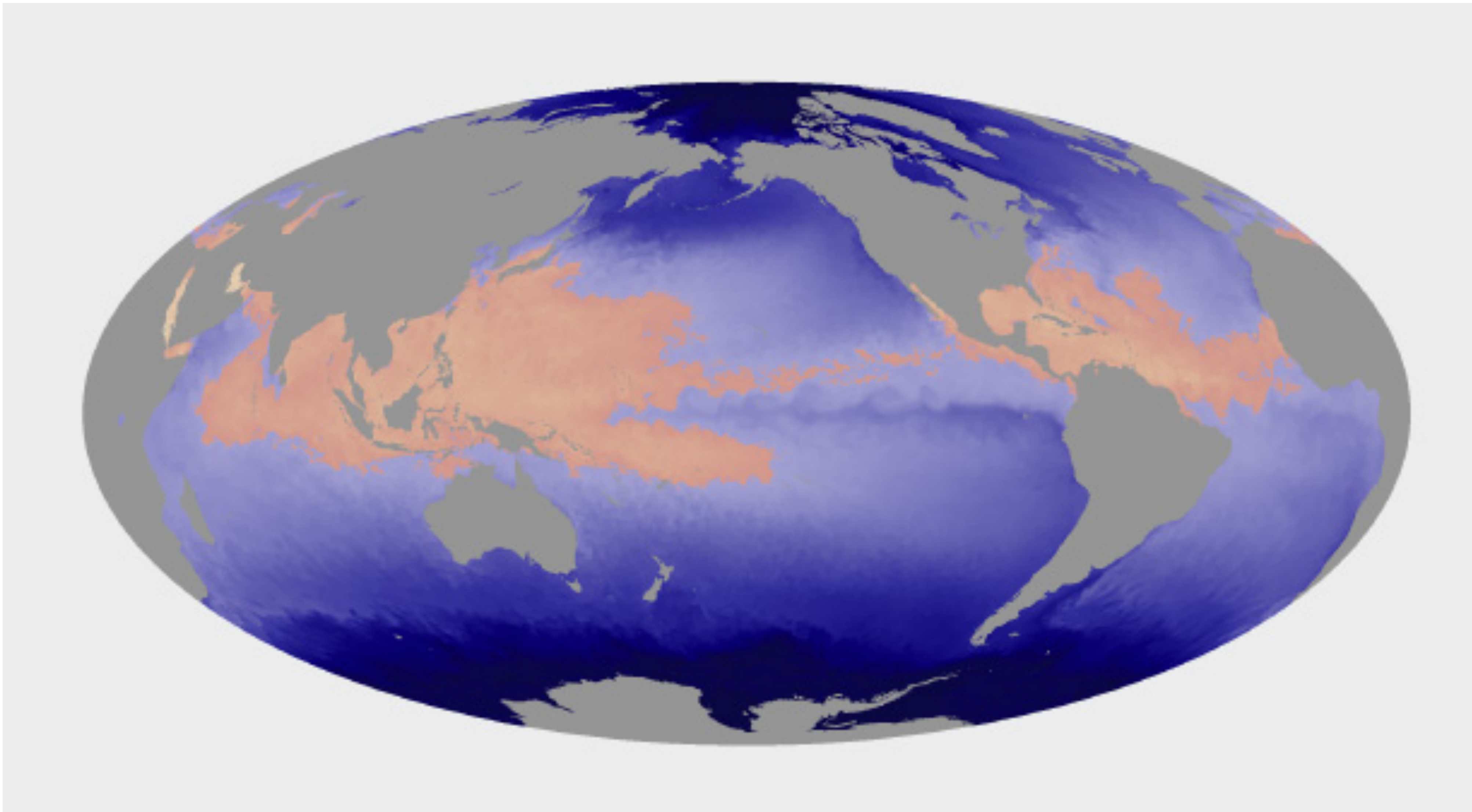


Color: Complementary Datasets



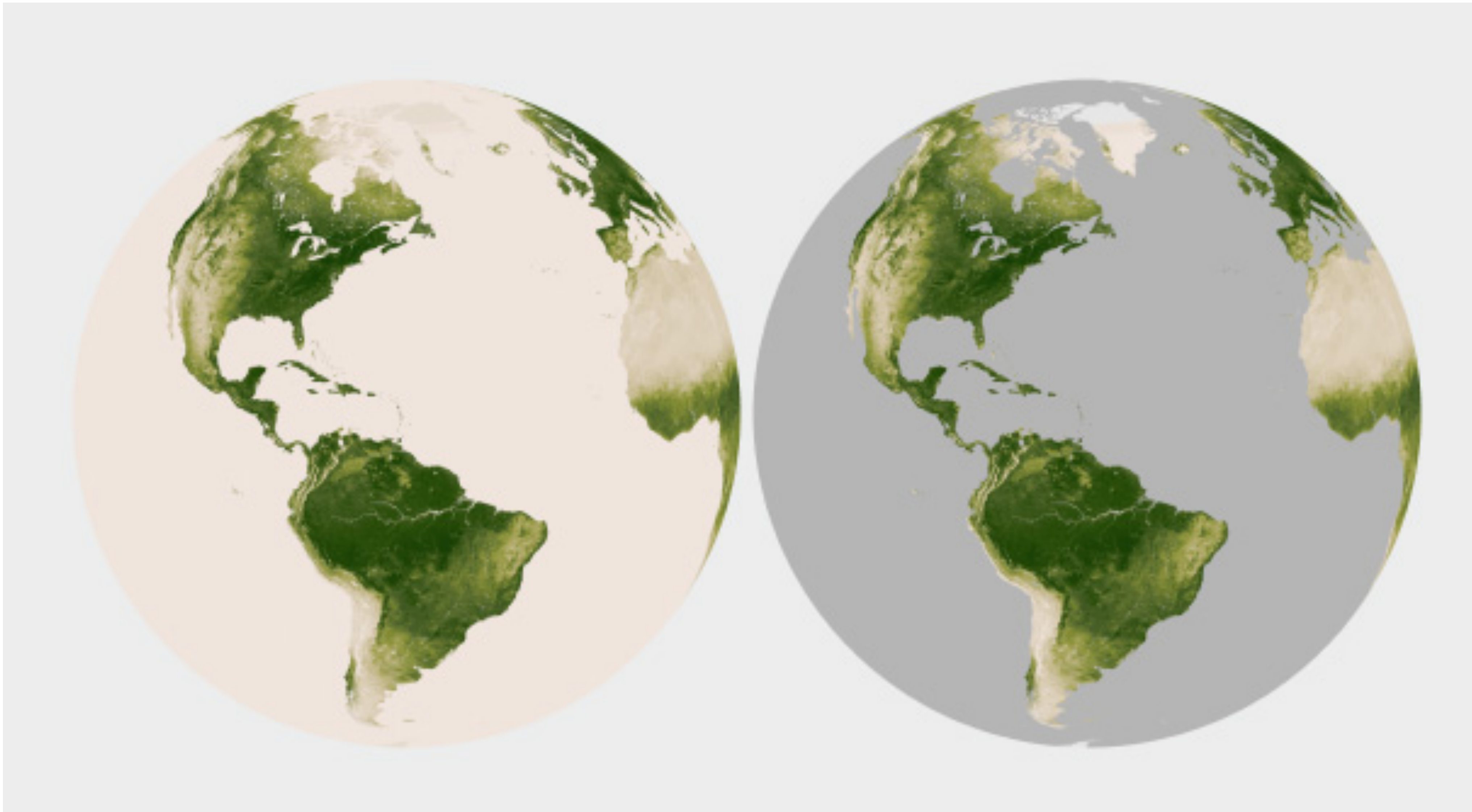
This map shows net primary productivity [a measure of the how much plants breathe (technically the amount of carbon plants take from the atmosphere and use to grow each year)] **on land and in the ocean. The two datasets are qualitatively different** (phytoplankton growing in the ocean, terrestrial plants on land), but quantitatively the same. **The green land NPP is easily distinguishable from the blue oceans, but the relative lightness matches for a given rate of carbon uptake**.

Color: Non-diverging Breakpoints



Hurricanes and other tropical cyclones are able to form and strengthen in waters over 82° Fahrenheit. This ocean temperature map **uses rose and yellow to distinguish the warm waters** that can sustain tropical cyclones **from cool water, colored blue**. (Map based on Microwave OI SST Data from Remote Sensing Systems.)

Color: Use Color to Separate Data from Non-Data



Missing or invalid data should be clearly separated from valid data. Simply replacing the **light beige used to represent water** in this map of land vegetation (left) **with gray causes the land surfaces to stand out**. (Vegetation maps adapted from the NOAA Environmental Visualization Laboratory.)

Texture

- Texture can be decomposed into a collection of fundamental perceptual dimensions. Researchers in computer vision have used properties such as regularity, directionality, contrast, size, and coarseness to perform automatic texture segmentation and classification
- Individual values of an attribute control its corresponding texture dimension. The result is a texture pattern that changes its visual appearance based on data in the underlying data set.
  - Grinstein et al. visualized multidimensional data with "stick-figure" icons whose limbs encode attribute values stored in a data element; when the stick-men are arrayed across a display, they form texture patterns whose spatial groupings and boundaries identify attribute correspondence

Texture: "stick-figure" icons

- **Two most important variables are mapped to the two display dimensions**
- **Other variables are mapped to angles and/or length of limbs of the stick figures.**

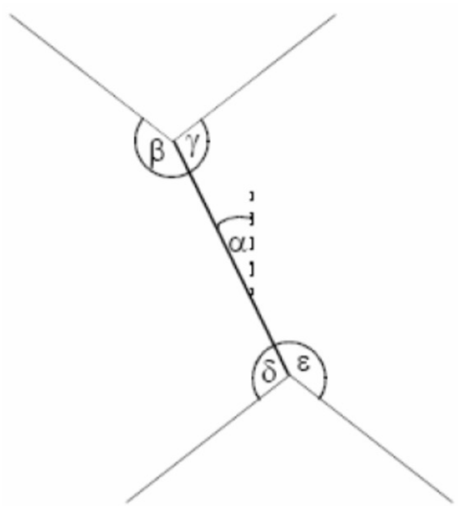
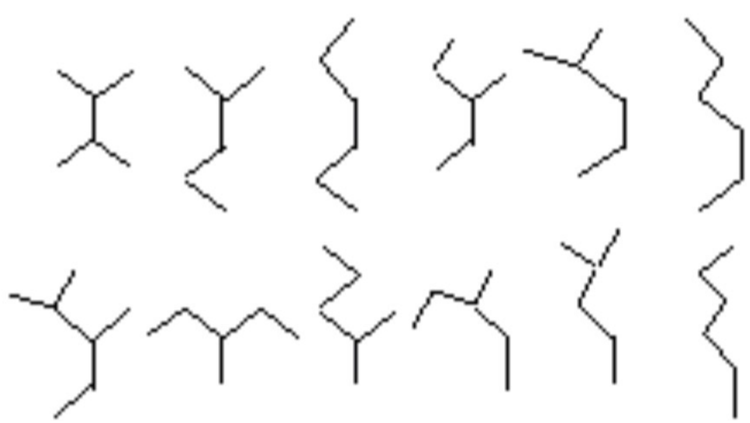
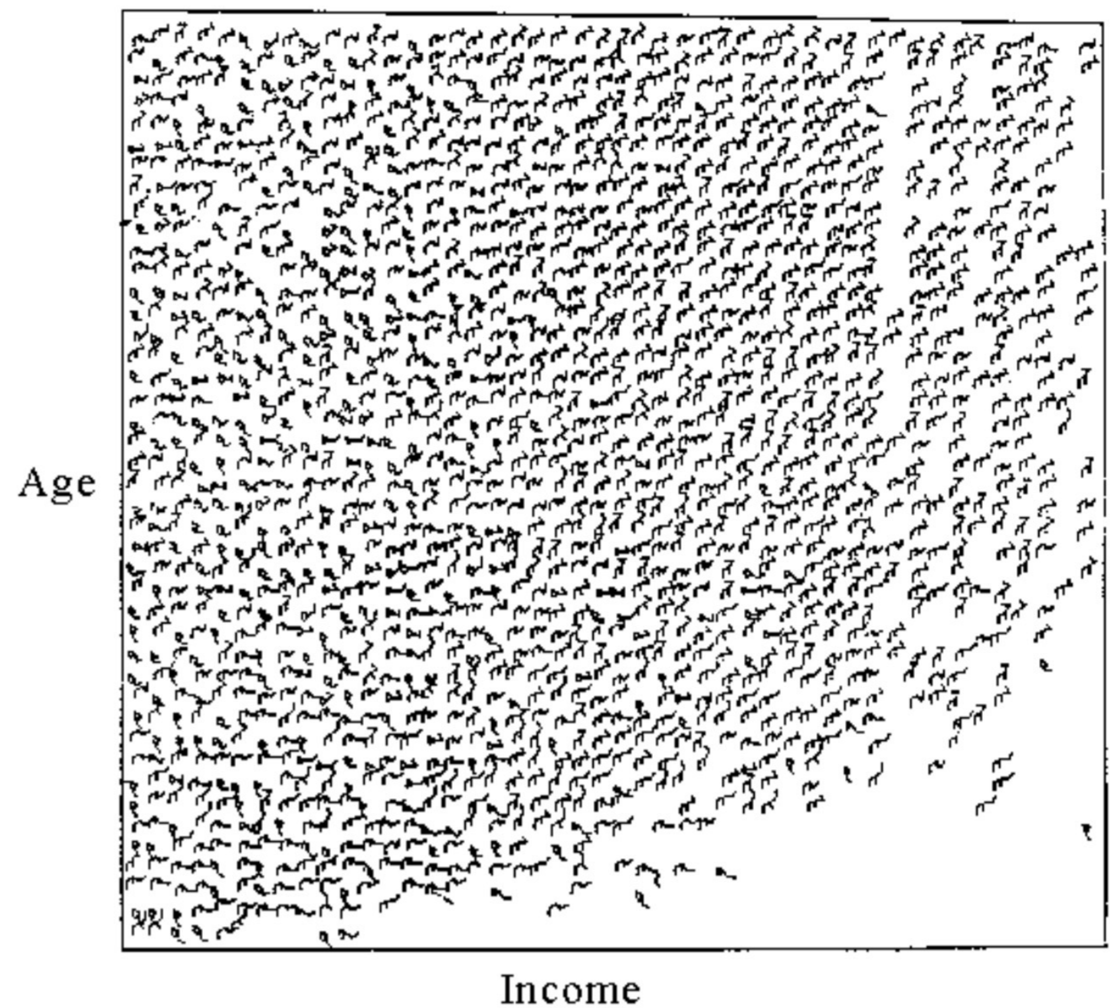


Illustration of a stick figure (5 angles and 5 limbs)



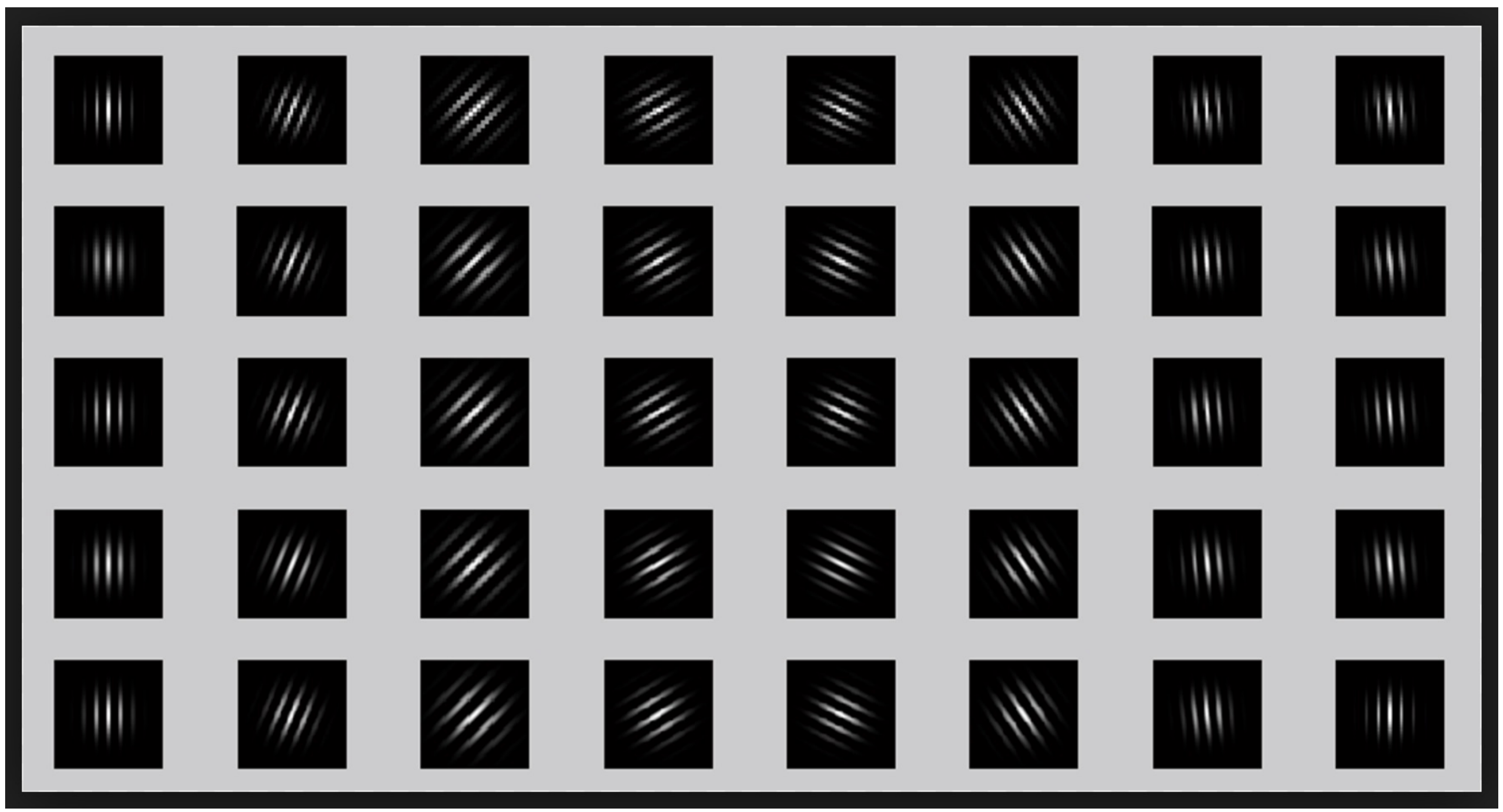
A family of 12 stick figures that have 10 features



Occupation, education levels, marital status, and gender are mapped to stick figure features

Texture: Gabor filters

- **Ware and Knight designed Gabor filters that modified their orientation, size, and contrast, based on the values of three independent data attributes**



In image processing, a **Gabor filter**, named after Dennis Gabor, is a linear filter used for edge detection

Texture: more …

- **Healey and Enns constructed perceptual texture elements (or pexels) that varied in size, density, and regularity; results showed that size and density are perceptually salient, but variations in regularity are much more difficult to identify.**

- **2D orientation can also be used to encode information: a difference of 15 degrees is sufficient to rapidly distinguish elements from one another. Certain 3D orientation properties can also be detected by the low-level visual system**

Motion

- **Motion is a third visual feature that is known to be perceptually salient**
- **Three motion properties have been studied extensively by researchers in psychophysics: flicker, direction of motion, and velocity of motion.**
- **In flicker frequencies F (the frequency of repetition measured in cycles per second) that are perceived as discrete flashes by the viewer.**
  - **frequency must vary from 2–5% to produce a distinguishable difference in flicker at the center of focus**
  - **and at 100% or more for distinguishable difference in flicker in the periphery**
- **Object velocity, direction of motion and pattern of motion**
  - **See Matthew O. Ward bag - 122 - 124**

10 Minutes break

https://youtu.be/n4no04822NQ

Metrics

Metrics

- **Absolute Judgment of 1D Stimuli**
- **Absolute Judgment of Multidimensional Stimuli**
- **Relative Judgment**
- **Expanding Capabilities**
- **The Relationship to Immediate Memory**
- **The Role of Recoding**
- **The Role of Focus and Expectation**

Metrics: Why?

- **How many distinct line lengths and orientations can humans accurately perceive?**
- **How many different sound pitches or volumes can we distinguish without error?**
- **What is our "channel capacity" when dealing with color, taste, smell, or any other of our senses?**
- **…**

- **These and related issues are important in the study of data and information visualization.**

Metrics: What?

- What graphical entities can be accurately measured by humans?
- How many distinct entities can be used in a visualization without confusion?
- With what level of accuracy do we perceive various primitives?
- How do we combine primitives to recognize complex phenomena?
- How should color be used to present information?

Metrics: Absolute Judgment of 1D Stimuli

- **Subject experimentation:**
  - **For each primitive stimulus, whether it be visual, auditory, taste, touch, or smell, we measure the number of distinct levels of this stimulus that the average participant can identify with a high degree of accuracy.**
  - **The results will follow an asymptotic behavior, e.g., at a certain point, increasing the number of levels being used causes an increase in the error rate, and no additional information will be extracted from the source stimulus.**
  - **Miller called this level the "channel capacity" for information transfer by the human.**

Metrics: Absolute Judgment of 1D Stimuli

- **Sound pitches (Pollack): The result was that the average listener could reliably distinguish 6 pitches. This is a channel capacity of 2.5 bits.**
- **Sound loudness (Gardner): the loudness of a sound was varied between 15–110 dbs. On average, 5 levels were accurately discerned, [2.3 bits].**
- **Salinity (Beebe-Center): Taste perception. With salt concentrations from 0.3 to 34.7 gm per 100 cc water, subjects were found to be able to distinguish just under 4 levels, on average [1.9 bits].**
- **Position on a line (Hake/Gardner): Varied the position of a pointer located between two markers. Most subjects were able to correctly label between 10 and 15 levels, though this increased with longer exposure [3.25 bits].**

Metrics: Absolute Judgment of 1D Stimuli

- **Sizes of squares** (Eriksen): the size of squares was varied. The capabilities of humans to accurately **classify the sizes was only between 4 and 5 levels** [2.2 bits].
- **Color** (Eriksen): In experiments that varied single color parameters, it was found that users could **correctly classify 10 levels of hue** and **5 levels of brightness**, or 3.1 and 2.3 bits, respectively.
- **Line geometry** (Pollack): In this experiment, **line length**, **orientation**, and **curvature** were tested. The results were: **2.6–3 bits for line length** (depending on duration), **2.8–3.3 bits for orientation**, and **2.2 bits for curvature** with constant arc length (while only 1.6 bits for constant chord length).

Metrics: Absolute Judgment of Multidimensional Stimuli

- **Dot in a square** (Klemmer/Frick): Given that a dot in a square is actually **two position measurements** (vertically and horizontally) we should get a capacity that is twice that of gauging the position of a marker on a line **(6.5 bits)**, but it was measured at **4.6 bits**.
- **Hue and saturation** (Halsey/Chapanis): **Combining hue and saturation** should have resulted in a capacity of **5.3 bits**, but it was measured at only **3.6 bits**.
- **Size, brightness, and hue** (Eriksen): In an experiment combining **geometry** and color, the size, hue, and brightness of shapes were varied. The sum of the individual capacities is **7.6 bits**, but a capacity of only **4.1 bits** was observed.

Metrics: Absolute Judgment of Multidimensional Stimuli

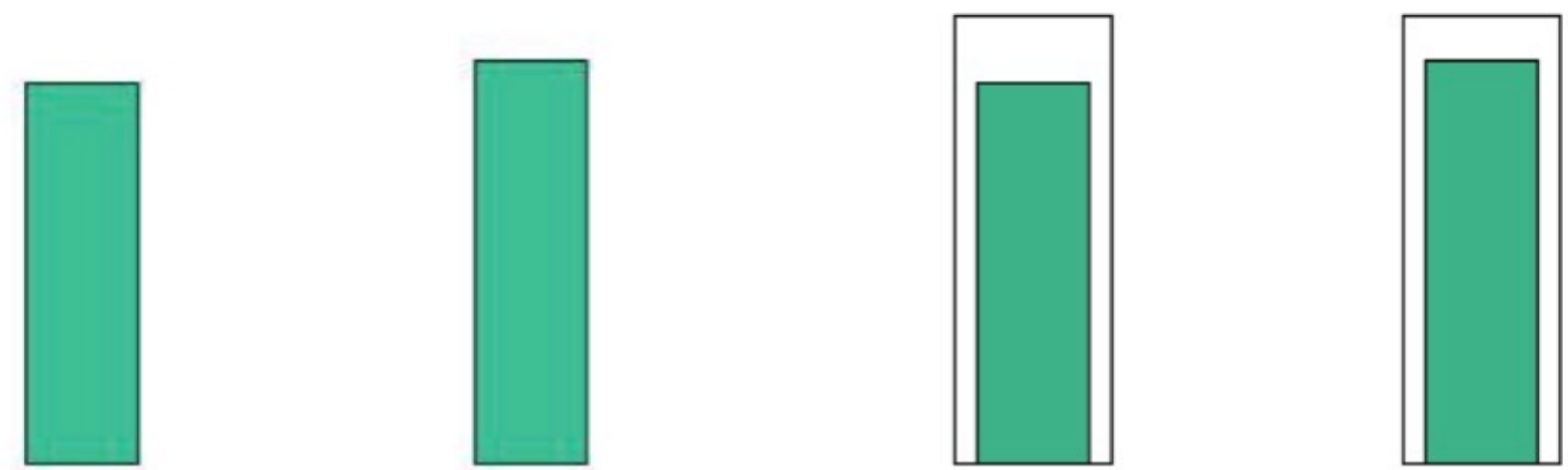
- **Combining different stimuli does enable us to increase the amount of information being communicated, but not at the levels we might hope.**

- **The added stimuli resulted in the reduction of the discernibility of the individual attributes.**

- **With that said, however, having a little information about a large number of parameters seems to be the way we do things.**

Metrics: Relative Judgment

- **William Cleveland emphasis, rather than on absolute measurement (classification), was on relative judgment: detection of differences, rather than extracting a numeric value.**



The boxes on the left are not the same size, but it is difficult to estimate the magnitude of the difference. The same boxes are shown on the right. The encapsulating frame makes it easier to gauge the relative difference between them.

Figure 3.33 - (Matthew Ward, et. all)

Metrics: Relative Judgment

- **William Cleveland experiments showed errors in perception ordered as follows (increasing error):**

  1. position along a common scale;

  2. position along identical, nonaligned scales;

  3. length;

  4. angle/slope (though error depends greatly on orientation and type);

  5. area;

  6. volume;

  7. color hue, saturation, density (although this was only informal testing).

Figure 3.33 - (Matthew Ward, et. all)

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  2. position along identical, nonaligned scales;
  3. length;
  4. angle/slope (though error depends greatly on orientation and type);
  5. area;
  6. volume;
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Metrics: Relative Judgment

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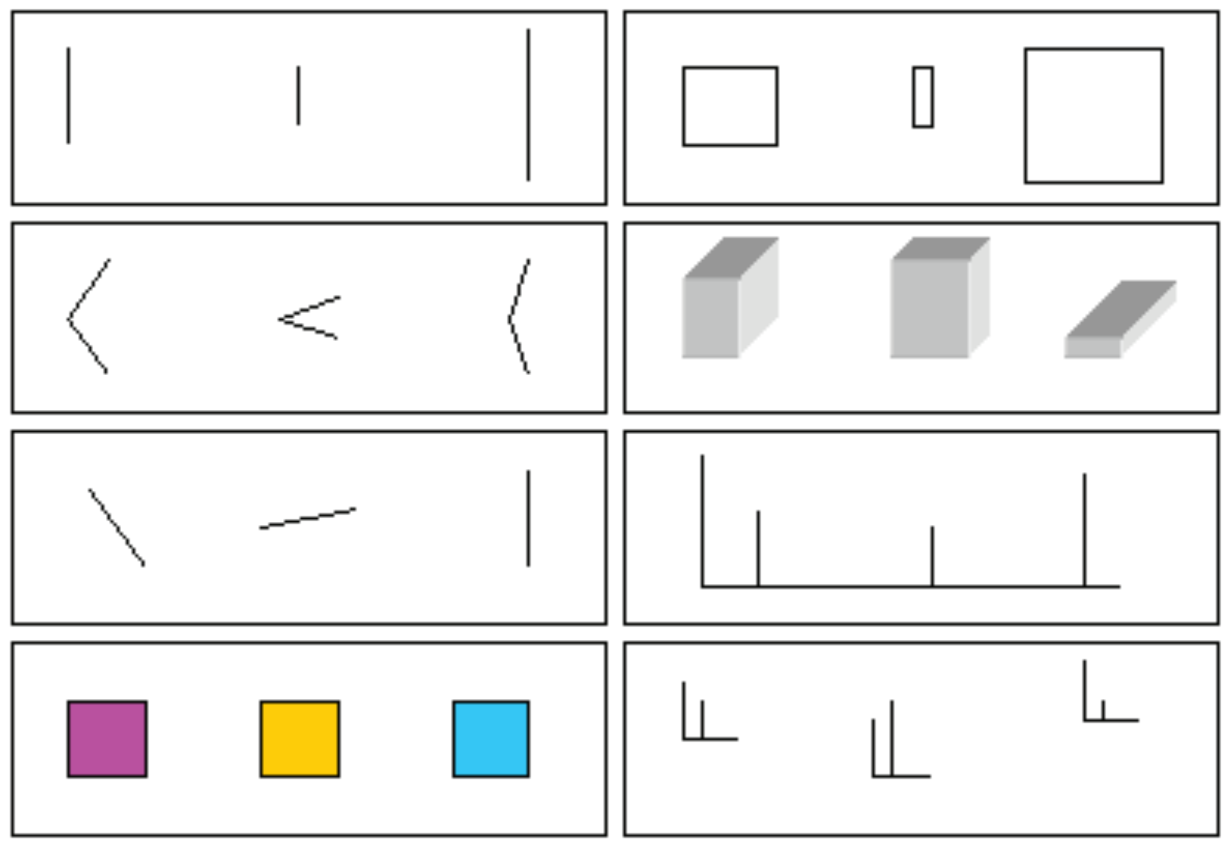


Examples of graphical attributes used in perceptual experiments. Left column (from top): length, angle, orientation, hue. Right column: area, volume, position along a common scale, position along identical, nonaligned scales.

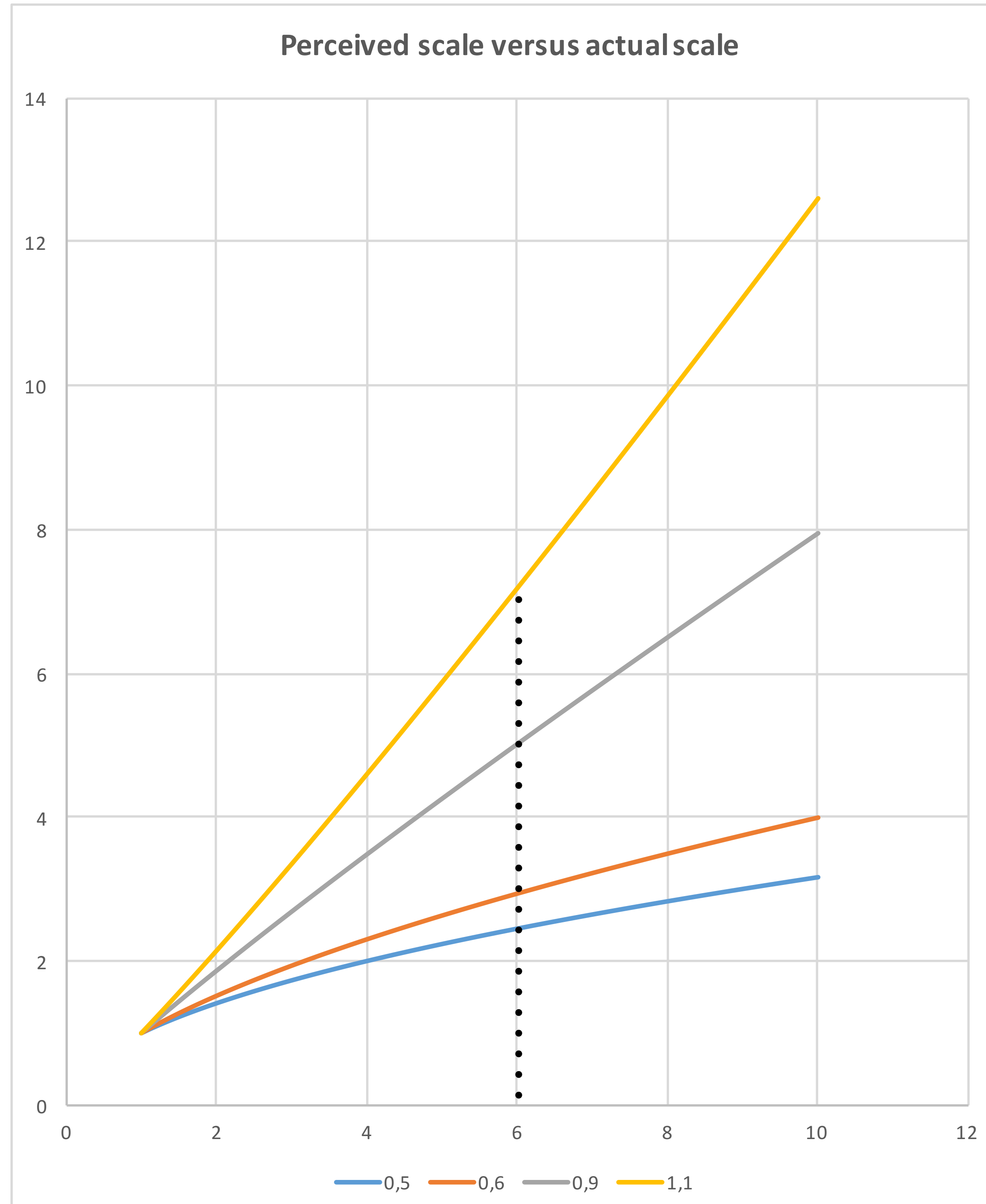
Figure 3.34 - (Matthew Ward, et. all)

Metrics: Weber's and Stevens's Laws

- **Weber's Law:**
  - **The likelihood of detecting a change is proportional to the relative change, not the absolute change, of a graphical attribute.**
- **Stevens' Law**
  - **The perceived scale in absolute measurements is the actual scale raised to a power.**
    - **For linear features, this power is between 0.9 and 1.1;**
    - **for area features, it is between 0.6 and 0.9,**
    - **for volume features it is between 0.5 and 0.8.**

Metrics: Weber's and Stevens's Laws

- **Stevens' Law**
  - **Linear features: [0.9 , 1.1]**
  - **Area features: [0.6 and 0.9]**
  - **Volume features [0.5 and 0.8]**
- **Real value of 6**
  - **Linear: perceived as 5 to 7**
  - **Area: perceived as 2.9 to 5**
  - **Volume: perceived as 2.5 to 4,2**



Metrics: Weber's and Stevens's Laws

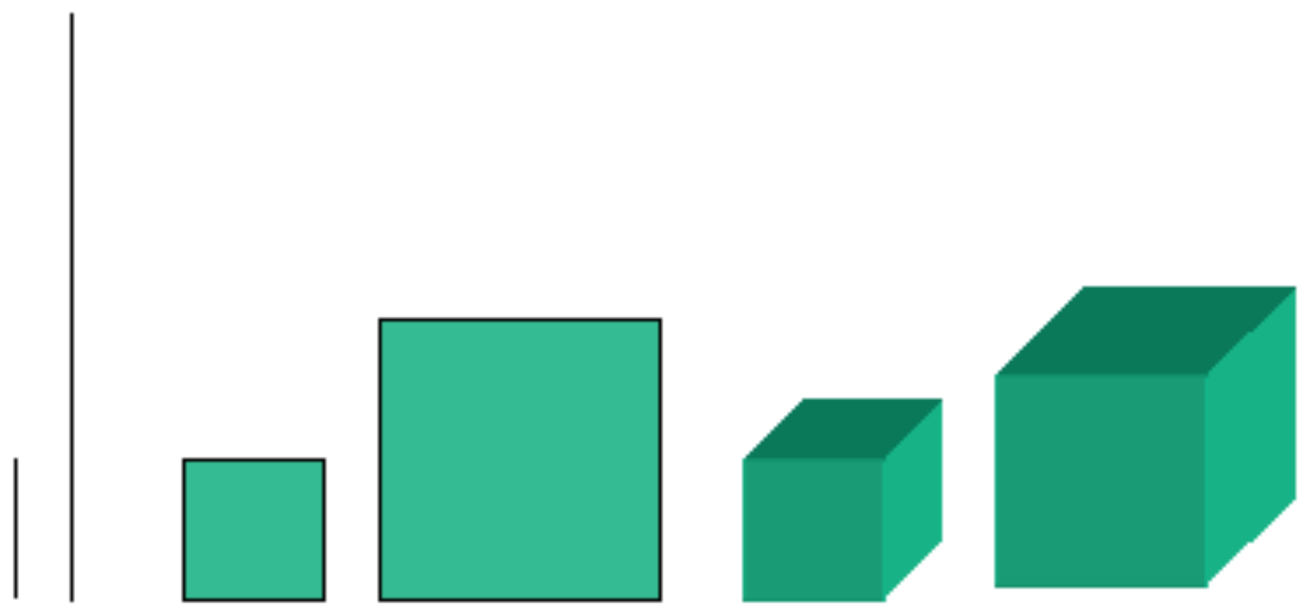


Illustration of Stevens' Law. The size ratio for each pair is 1:4. This magnitude is readily apparent in the lines, but it is easily underestimated in the squares and cubes.

Figure 3.35 - (Matthew Ward, et. all)

Expanding Capabilities

- **If we need to communicate information with a higher capacity, we must investigate strategies for expanding our capabilities:**
  - **reconfigure the communication task to require relative, rather than absolute, judgment. This is why adding grid lines and axis tick marks is a useful and powerful addition to a visualization**
  - **increasing the dimensionality with caution and in a limited way**
  - **reconfigure the problem to be a sequence of different absolute judgments, rather than simultaneous stimuli.**

Other aspects to take into account

- **The Relationship to Immediate Memory**
  - **short- term memory is used for very short-term recall, often immediately after a stimulus has been received. Studies have shown the span of short- term memory to be approximately 7 items (or less)**
- **The Role of Recoding**
  - **Recoding is the process of reorganizing information into fewer chunks, with more bits of information per chunk.**
  - **Recoding differs from person to person**
- **The Role of Focus and Expectation**

Further Reading and Summary

Q&A

Further Reading

- **Pag 118 - 163 from Interactive Data Visualization: Foundations, Techniques, and Applications, Matthew O. Ward, Georges Grinstein, Daniel Keim, 2015**

- **Subtleties of Color**
  - **http://earthobservatory.nasa.gov/blogs/elegantfigures/2013/08/05/subtleties-of-color-part-1-of-6/**

- **Color Models**
  - **http://dba.med.sc.edu/price/irf/Adobe_tg/models/main.html**

- **Check:**
  - **http://colorbrewer2.org**

What you should know

- **The difference between the light we see and the colors we perceive**
- **The RBG and the CMY color models. Their relations. Why they are not appropriate for perception**
- **The Munsell's color model. The goals for the perceptual models**
- **The notion of color map, and the different types of color maps**
  - Color maps for sequential data; for divergent data, for categorial data
- **The importante of color blindness to choose a color map**
- **The most important rules to choose or build a color map**
- **How to use texture to convey information.**

What you should know

- What is our "channel capacity" when dealing with color, taste, smell, or any other of our senses.
- What graphical entities can be accurately measured by humans
- How many distinct entities can be used in a visualization without confusion
- With what level of accuracy do we perceive various primitives
- What is Absolute Judgment of 1D Stimuli
- What is Absolute Judgment of Multidimensional Stimuli
- What is Relative Judgment
- What are the Weber's and Stevens's Laws
- Strategies to expand our communication capabilities

Recommended activities

- **Start to seek for the elements to choose your subject**
  - **Data**
    - **https://www.kaggle.com/datasets**
    - Look for data-providers. For instance look at this:
      - https://sqlbelle.com/2015/01/16/data-sets-for-bianalyticsvisualization-projects/
      - https://www.springboard.com/blog/free-public-data-sets-data-science-project/
      - http://infosthetics.com
      - http://www.ipcc-data.org/observ/clim/cru_ts2_1.html
  - **Questions that worth (at least to you) to be addressed**
  - **Type of visualizations that can be useful**
  - **Papers that address the same or similar, or just related to the problems that you consider**

Q&A